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TIRE RECYCLING AND REUSE INCENTIVE

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This report describes a series of strategies to deal with the disposal/recovery of scrap tires. These tires form a particularly intractable form of solid waste since they do not decompose, have an adverse effect on incinerators and air emissions, and disrupt the compaction process in sanitary landfills. The options for the disposal or recovery of used tires are described by this study as well as research into new methods of tire recovery . Rubber reclaimed from scrap tires can be used in new tire manufacture but lacks the uniformity, tensile strength, heat resistance and abrasion resistance to be used in very large concentrations. Pyrolysis, hydrogenization and related processes for separating tires into substances that may be recycled into tire production or sold as fuel, although workable on a laboratory scale, have not yet been proven commercially. The incorporation of chopped tires into an interface layer of asphalt between a deteriorated road and its new surfacing is a promising use of tires. A series of strategies was devised under which various economic, regulatory, educational, and research & development activities were combined to provide incentives to encourage the reuse of tires or improve tire disposal practices.

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PREFACE

In gathering information for this study, protection of proprietary information with respect to the use of reclaimed rubber in new tires was a recurring problem. We were not able to obtain exact figures from manufacturers on the extent to which reclaimed rubber is used in specific tires. Our conclusion, that a marked increase in the use of reclaimed rubber in new tires would not be in keeping with performance requirements, was, however, supported in general terms by all tire industry representatives with whom we spoke.

In an extension of this study, implementation of the selected strategy was described in detail. Draft legislation was prepared together with an expanded description of how the strategy would operate generally. Special attention was given arrangements that would permit cooperative action among municipalities and state governments to reduce the cost and increase the effectiveness of tire re-use and recycling.

Finally, the method of strategy selection employed in this study and described in Appendix A, although preferred by the authors for the purposes of this work, is only one of a number of similar decision-making procedures that might be used in such a sorting process.

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The authors wish to acknowledge their special indebtedness to the extensive study of solid waste problems in the tire manufacturing and associated industries, *Rubber Reuse and Solid Waste Management* by Robert J. Pettigrew, Frank H. Roninger, Walter J. Markiewicz and Michael J. Gransky, Uniroyal Chemical Division of Uniroyal Inc., carried out for the Solid Waste Management Office.* Particular thanks are also due to the following persons and organizations for their generous contributions of time and information:

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SUMMARY

Scrap tires are a particularly intractable form of solid waste because they do not decompose, can have an adverse effect on incinerators and can disrupt the compaction of sanitary landfill.

This report undertakes to select a national strategy to reduce the growing accumulation of scrap tires. A flow chart of the tire market was prepared showing the volume of new tires moving from manufacturers through distribution channels to retail outlets, and consumers, and of used tires from consumers through retail outlets, to retreaders and to final disposition.

Each major segment of the market was examined and its dimension and activities studied in sufficient detail to permit estimation of the effects that changes in other sectors would have on the sector under study. Within each sector the decision points,at which choices are made that affect the direction or quantity of the flow of tires,were identified. For each decision point, the factors that would tend to influence the decision were displayed.

A survey was undertaken of the end uses to which rubber tires are, or would be, put.

A series of strategies was devised under which various economic, regulatory, educational, and research and development activities were combined to provide incentives to encourage reuse of tires or improve tire disposal practices. After developing a series of weighted criteria, these strategies were evaluated and a preferred strategy selected. The legislative, administrative and financial requirements of the selected strategy were described.

CONCLUSIONS

(1) Rubber reclaimed from scrap tires by existing reclaiming technology lacks the uniformity, tensile strength, heat resistance and abrasion resistance to be used in concentrations greater than a few percent in high performance pneumatic tires.

(2) Pyrolysis, hydrogenization, and related processes for separating tires into substances that may be recycled into tire production, although workable on a laboratory scale, have not yet been proven commercially. Incorporation of chopped tires into an interface layer of asphalt between a deteriorated road and its new surfacing is a promising use of tires but is also still in an experimental phase. Other experimental end uses are also being researched. Under the circumstance it would be premature to select a single process or end use for scrap tires as a basis for a national tire recycling or reuse program.

(3) It appears likely that the optimum choice among recycling, economically productive forms of reuse, and environmentally acceptable modes of tire disposal not related to recycling or reuse, will be different in different regions of the United States, and that a strategy that permits regional variation will be desirable.

(4) The strategy that was selected used the existing federal excise tax on new tires and retread rubber as a source of funding. It permits state and municipal governments to choose among a number of approved end uses or forms of disposal previously approved by the Solid Waste Management Office. The federal funds are made available first to pay capital costs for disposal or reuse systems and, later, as incentive payments to the state or municipal authority based on the number of tires disposed of by that authority through an authorized end use or form of disposal.

The selected strategy would permit state and municipal officials flexibility in the selection of an end use or means of disposal appropriate to their region and permit remedial action to begin now while allowing for the introduction of new technologies when they become available.

1 follows

CHAPTER 1

INTRODUCTORY CONSIDERATIONS

In 1969, 229.9 million new pneumatic tires of all kinds (including 197.7 million passenger car and truck tires) were shipped by domestic tire manufacturers in the United States;[1] an additional 14 million new tires were imported either as original equipment on imported cars or separately.[2] More than 46.5 million retreaded tires were sold the same year.[3] After their useful lives have expired, these tires are discarded at a rate of approximately 180 million per year.*

Although they make up only a small fraction of our national solid waste management burden, tires are among its more intractable components. In the past, tires were dumped and burned in the same manner as other refuse. To the extent that high-temperature, forced-draft incineration, and sanitary landfill have replaced the earlier practices, however, tires have become a more serious problem. Tire burning in simple incinerators generates very large quantities of unburned hydrocarbons. The highly visible and noxious smoke from such burning can be controlled adequately to meet emerging air quality standards only by use of an augmented air supply, followed by scrubbers or electrostatic precipitators. Whole tires burned with the augmented air supply in modern incinerators are troublesome not only because of their combustion byproducts, but also because their concentrated high thermal content damages incinerator grates and refractories. Whole tires, incorporated in bulk into a typical sanitary landfill, spring back to their former shape after compaction and tend to work their way to the surface during settling, finally emerging through the landfill surface. Tires are extraordinarily durable and biologically inert, and are extremely slow to decompose.

Although tires are a quantitatively small component of the waste stream, the preceding attributes make them particularly promising candidates for recycling or reuse.

---

[1] Rubber Industry Facts, 1970. New York, Rubber Manufacturers Association, 1971.

[2] 1970 Automobile Facts and Figures. Detroit, Automobile Manufacturers Association, 1970.

[3] Tire Retreading Institute. Unpublished data.

*The exact rate of discard is not known. Estimates vary from 100 million to 200 million. The 180 million used in this report is taken from Goodyear News Bureau release No. 14982-970, September 24, 1970, p. 2.

This study is an effort to determine what pattern of incentives or disincentives will promote most successfully the development of a pattern of recycling or reuse so as to prevent tires from entering the solid waste stream.

Initially this report was based on the assumption that by using existing conventional processes the rubber in automobile tires could be separated from other material in tires and converted into new passenger car tires. This assumption, however, was not supported by subsequent research. Such separation and conversion, known generically as rubber reclaiming, do exist but the product produced by them lacks the uniformity, tensile strength, heat resistance, and abrasion resistance of new rubber.[4] Reclaimed rubber is incorporated in small amounts into tire compounds to make the new rubber in the compounds easier to manipulate, but cannot be used in concentrations greater than a few percent in high performance pneumatic tires.

This inability to recycle using current technology is a critical factor which distinguishes solid waste strategies affecting tires from those for other forms of solid waste. For example, using existing technology, automobile hulks can be completely recycled into new steel provided someone is willing to pay the cost of removing copper from the hulk, either manually or by shredding and electromagnetic sorting, before it is melted. The recycling of junked cars is essentially an economic problem that can be solved with economic incentives.[5] Technology for recycling old tires into new ones will require the breakdown of rubber into the organic compounds from which synthetic rubber is constructed. This breakdown, while possible on a laboratory scale, is as yet unproved on a commercial level.

In the case of tires, the small amount of reclaimed rubber presently used in new-tire production does not reflect a lack of economic incentives but a lack of technological capability. There appears to be little prospect of improving this capability sufficiently to make recycling of reclaimed rubber an effective means of scrap tire disposal. The output of the reclaiming industry in 1968 was lower than that in 1958, and was expected to decline further in the 1970's.[6] Increasing demands on automobile performance and road engineering suggest that this decline is not likely to be halted. Highway speeds are increasing by about ½ mile per hour per year. Reclaimed rubber is not well suited to tires intended to be operated at high speeds.

For these reasons, it is necessary to consider other alternatives to the direct recycling of scrap tires into new tires by rubber reclaiming. Accordingly, this study has evaluated a wide range of possibilities involving: (1) indirect recycling (i.e., recycling into other products or industries); (2) advanced recycling (recycling involving tire materials and tire construction that are not yet within the reach of tire technology); (3) methods of disposal which do not involve economically productive reuse but which are less insulting to the environment than "traditional" methods of disposal; (4) strategies for decreasing the amount of waste produced in the first place, either by retreading (extending the life of the carcass) or by achieving longer wear in the original tires.

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[4] Goodyear Tire and Rubber Company. Unpublished data.

[5] The Automobile Cycle; An Environmental and Resource Reclamation Program. Washington, U.S. Government Printing Office, 1971.

[6] Pettigrew, R.J., F. Roninger, W. D. Markiewicz, and M. J. Cransky. Rubber Reuse and Solid Waste Management. Pts. 1 and 2. Washington, U.S. Government Printing Office, 1971.

The tire market has another feature of its waste recycling operation that distinguishes it from other waste recycling operations. The sale of retread tires currently accounts for approximately 22 percent of replacement tire sales. Nearly all purchasers of replacement tires leave their old tires with the retailer from whom they buy their new tires. Retreaders typically obtain tire carcasses in bulk by buying and collecting the entire stock of discarded tires from new tire retailers. Depending upon the quality standards of the retreader, only one-fourth to one-half of the tires he purchases are of good enough quality to retread.[7] (We have used 35 percent as an average figure throughout this report.) The result of this culling process, however, is that tires tend to be segregated from other waste, and, to a degree (sometimes a very great degree), centrally collected by the existing market structure before they are disposed of.

Taken together, these two unique characteristics of the scrap tire problem made it necessary to consider from the beginning of the study what should be done with unretreadable tires once they were collected. This need to identify one end use or several compatible end uses for unretreadable tires has been a companion problem to the central recycle incentive study.

Methodology

This study uses a systems approach coupled with a series of weighted criteria for selecting alternatives once they have been identified.

The following steps were employed in using this approach to select a reuse strategy. As a result of interviews and correspondence with manufacturers, distributers, retailers, retreaders and reclaimers, a model was prepared which showed the relationships of the most significant sectors or the tire market to one another and the volume of tires moving from sector to sector. The points at which decisions affect flow were identified, as were the alternatives to be decided among at each decision point and the considerations affecting these decisions.

A brief survey was made of existing and possible end uses, relying partly upon earlier studies for the Solid Waste Management Office and partly upon interviews with corporations in and outside the tire industry now working on end uses for tires. We then identified what we believe to be the most promising end uses: extended tire life, expanded retreading, power production, reef construction, reuse of old tires intact, roadbuilding, carbon black recovery, distructive distillation, hydrogenization, protein manufacture, incineration, and landfill.

The following criteria were developed for evaluating strategies:

How soon would the strategy be technically feasible?

How much land/air/water residual would the strategy leave?

---

[7] Staff interviews.

How much cost per unit would be unrecovered in this strategy?

How much non-monetary benefit would be recovered?

How long would application of the strategy be possible?

How much of each year's output of non-retreadable tires would the strategy absorb?

How much would the strategy change the existing market structure?

How compatible would the strategy be with other solid waste management practices?

These criteria were first weighted by having participating staff members divide 100 units of weight among all the criteria, and by establishing mean values.

A series of eleven strategies was devised which incorporated the most promising end uses. The strategies were then evaluated according to these criteria. A strategy was selected and a plan prepared setting forth the action needed to implement it.

The Model

The tire waste stream is the output of a number of market segments (Diagram 1.1).

The stream begins with the tire manufacturer, who utilizes steel bead, steel wire, fiber glass, rayon, nylon, and polyester cord and synthetic, natural, and reclaimed rubber to produce tires for passenger cars, trucks, buses, farm and other off-road vehicles, bicycles and aircraft. The tire manufacturers sell between one-quarter and one-third of their output to automobile manufacturers; the remainder they sell or distribute either directly or through wholesalers, to tire retailers (filling stations, garages, manufacturers' outlets, department stores, mail order houses, and independent tire dealers). The consumer obtains tires in one of two ways: either as original equipment from an automobile retailer with the purchase of a vehicle, or as replacements from a tire retailer when the original tire wears out. At the time that the consumer purchases his new tire, he typically leaves his worn-out tire with the tire retailer from whom he buys its replacement. The small-volume retailer treats the worn-out tire as waste and disposes of it through municipal waste disposal channels. The larger-volume retailer sells an accumulation of discarded tires either through a carcass dealer or directly to a retreader, who then selects a minority of the used tires for retreading and resale through tire retailers, and disposes of the remainder. Less than 5 percent of the tires thus disposed of are recycled through the rubber reclaiming and tire splitting industries; the rest are dumped or, more rarely, incinerated.

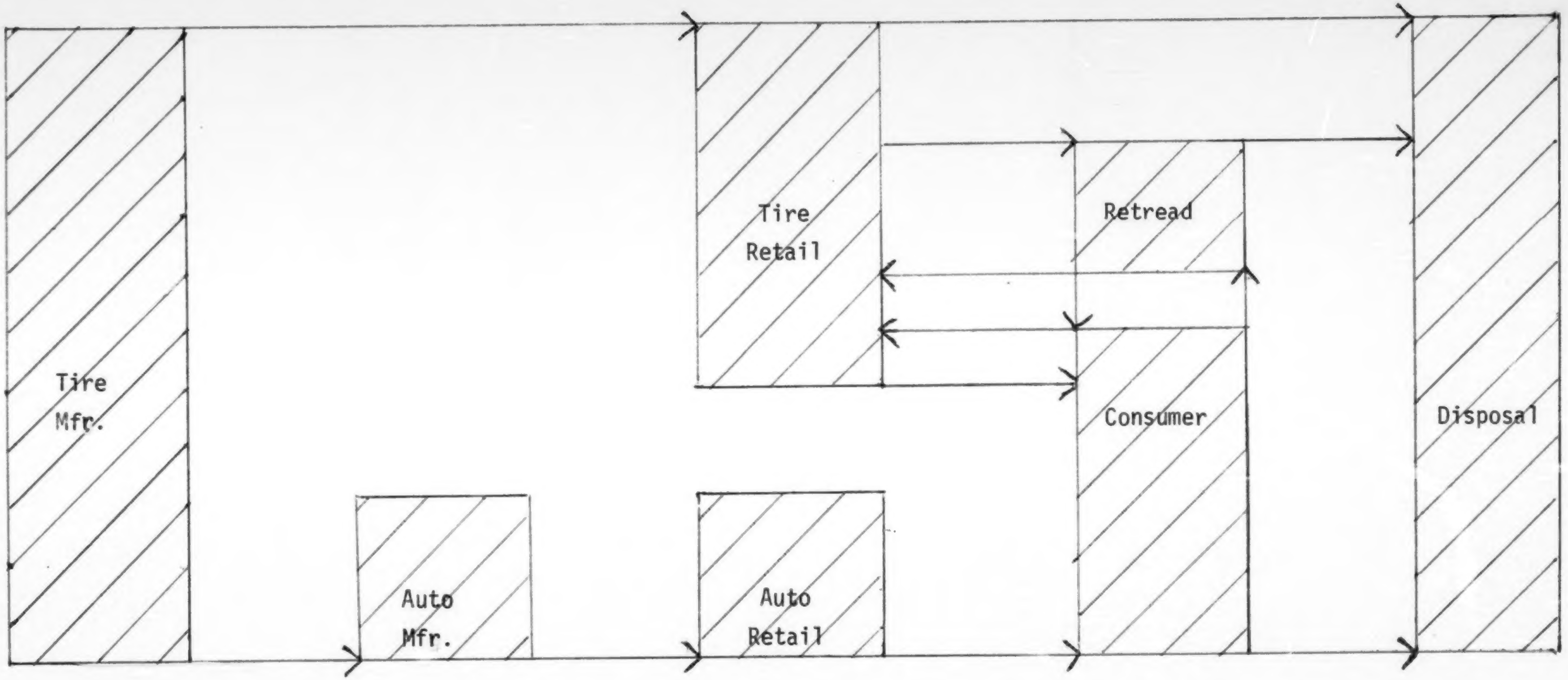
Tire
Mfr.
Auto
Mfr.
Tire
Retail
Auto
Retail
Retread
Consumer
Disposal

DIAGRAM 1.1

TIRE MARKET MODEL

The arrows show the main flows of tires from their manufacture to their disposal.

The model (Diagram 1.1) was repeated in Diagram 1.2 with the addition of flow figures showing, in millions of tires, the principal movement of new tires, used tires, retreaded tires, and scrap tires. (The term "scrap tires" is used throughout the study to mean tires that are not suited for retreading because of excessive wear or defects, as well as tires that are for any other reason discarded as solid waste.) It is repeated again in Diagram 1.3. which shows the five areas where we believe incentives could increase recycling or reuse of tires in ways that would reduce the incidence of tire dumping.

Area 1 represents the tire manufacturing industry which, by its selection of tire materials and tire specifications and by quality control, has a major effect on the length of new tire life and the suitability of used tires for retreading. Although the tire wholesalers and distributors supply the connection between the manufacturers and the retailers, they do not have an independent discretionary role in the design or movement of tires and, therefore, are not covered in detail.

Area 2 represents the automobile manufacturing industry, the largest single customer for new tires and the customer whose tastes and specifications dictate many of the decisions made in Area 1.

Area 3 encompasses the consumer whose buying patterns and maintenance practices have a direct bearing on the durability of the new tires he buys, the mileage that he gets from tires of a given specification, the suitability of his used tires for retreading, and the success with which retreads compete for sales against new tires.

Area 4 represents the retreading industry which, at the present, carries out the only major recycling function within the tire waste stream. (The reclaiming industry has a minor role in that some tires are made into reclaimed rubber and some reclaimed rubber is used in tire manufacture. As explained in the Introduction, however, the amount is small and diminishing every year. For this reason we do not treat the reclaiming industry as a promising opportunity for recycling or for improved end use incentives.)

Finally, Area 5 encompasses the entire subject matter of disposal. At the present time, this area represents the point at which nearly all tires, some after one or more retreadings, enter the solid waste stream.

Explanation of Tire Market Flow Chart

Manufacturers shipped a total of 146.6 million tires (Diagram 1.2) to retailers in 1969. All of these tires are classified as "new replacements", as distinguished from "original equipment" tires that are shipped directly to the manufacturers of motor vehicles.

Tires passing from retailers to consumers include both new replacements and retreads. Since retreads for trucks and buses generally pass directly from retreaders to consumers, they are not included in the retailer-consumer flow. Also not included are some 53 percent of the passenger car retreads which, similarly to trucks and buses, pass directly from retreaders to consumers (many of them in purchases for fleets). The remaining 47 percent

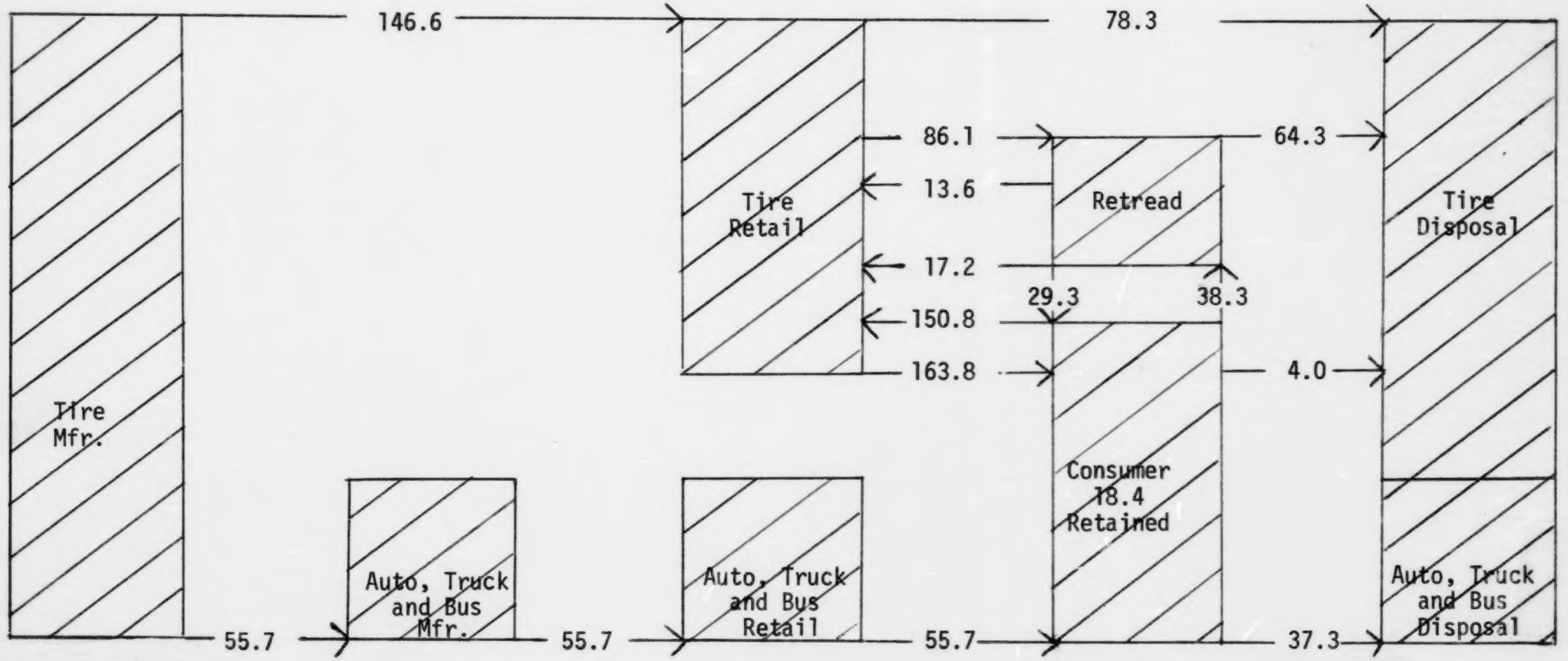
146.6
78.3
Tire Mfr.
Tire Retail
86.1
13.6
17.2
150.8
163.8
Retread
64.3
29.3
38.3
4.0
Tire Disposal
Consumer 18.4 Retained
Auto, Truck and Bus Mfr.
Auto, Truck and Bus Retail
Auto, Truck and Bus Disposal
55.7
55.7
55.7
37.3

DIAGRAM 1.2

U.S. TIRE MARKET FLOW CHART

Passenger Car, Truck and Bus; does not include bicycle, industrial, agricultural, aircraft or motorcycle tires, imports, or relatively minor market segments.

Note: Figures shown above were calculated from preliminary estimates and vary slightly from year-end data on page 1.

Unit of measure: millions of tires.

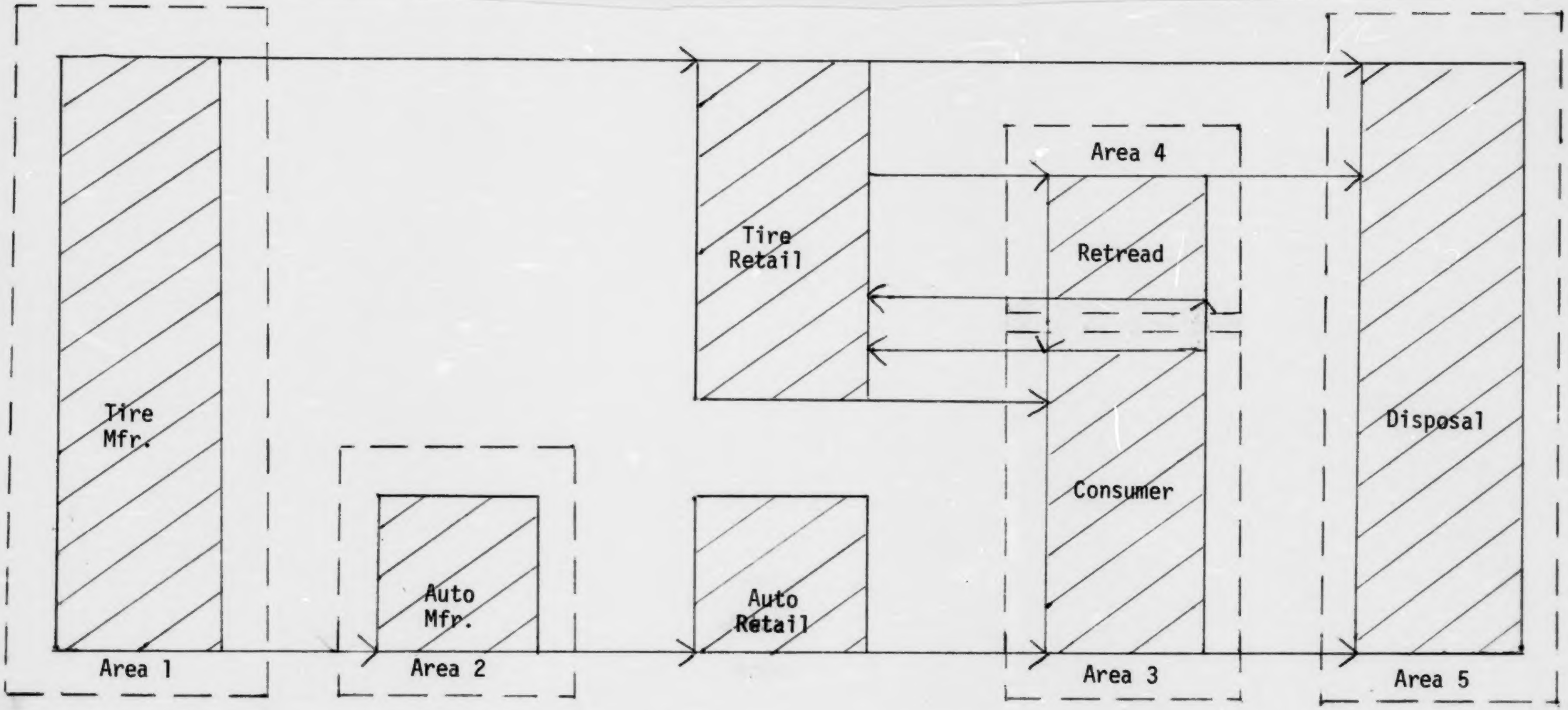
Tire Mfr.
Area 1
Auto Mfr.
Area 2
Tire Retail
Auto Retail
Area 4
Retread
Consumer
Area 3
Disposal
Area 5

DIAGRAM 1.3

TIRE MARKET: KEY AREAS

of passenger car retreads, or 17.2 million tires, are sold to consumers by retailers. These, combined with the 146.6 million new replacements, bring the total retailer-consumer flow to 163.8 million tires (Diagram 1.2).

The number of used passenger tires returned to retailers in exchange for new replacements is equal to 98 percent of 146.6, the number of new (129.3) and retread (17.8) replacement tires sold by retailers, or 143.6. To these are added 7.2 used truck and bus tires, for a total consumer-retail flow of 150.8 million (Diagram 1.2).

The flow of tires from retailers to retreaders is equal to the total number of passenger car used tires accumulated by retailers (truck and bus used tires generally by-pass retailers), and subsequently examined by retreaders for possible reuse. Since approximately 35 percent of the tires examined are accepted for retreading and the number of passenger car tires retreaded is 36.5 million, the total number of tires examined is 36.5/.35 million or 104.3 million. The flow of tires from retreaders back to retailers is simply the number of passenger car retreads sold by retailers, which is estimated to be 47 percent of the total number (36.5 million/.35) of passenger car retreads sold, or 17.2 million (Figure 1.2).

The flow of tires from retail to disposal consists of passenger car tires not examined by retreaders, plus passenger car tires examined by retreaders but returned to retailers as unusable. (Some retreaders return unusable tire carcasses to the retailers who supply them; some dispose of them directly.)

Of the 104.3 million car tires examined by retreaders, 18.2 million come directly from the consumer (see calculation below) and the remaining 86.1 million are sent from the retailer to the retreader.

Of the 143.6 used car tires accumulated by retailers, 86.1 million are sent to retreaders (as above) and the remaining 57.5 are disposed of.

Unretreadable car tires returned to retailers by retreaders are estimated to be 20 percent of those rejected by retreaders, and the number rejected equals 65 percent of the 104.3 million tires examined, or 67.8 million. Twenty percent of this number is 13.6 million. This, combined with the 57.5 million tires not examined, and 7.2 million truck tires, amounts to a total retail-disposal flow of approximately 78.3 million used tires (Figure 1.2).

The flow from retreaders to consumers equals 53 percent of the total passenger car retread sales of 36.5 million, or 19.3 million, plus all of the 10 million truck and bus retreads, for a total of 29.3 million (Figure 1.2). The flow from consumers to retreaders is equal to the difference between the total number of tires returned in exchange for new or retreaded tires, and the number returned to retailers only. Since returns to retailers amount to 89 percent of the total used tires for passenger cars and 25 percent of the total used tires for trucks and buses, the returns to retreaders comprise the remaining 11 percent for passenger car replacements and 75 percent for truck and bus replacements. Eleven percent of 165.8 million is 18.2 million and 75 percent of 27.3 million is 20.1 million. These add up to a total consumer-retreader flow of 38.3 million (Figure 1.2).

The flow from retreaders to disposal is equal to 80 percent of the 67.8 passenger car tires rejected by retreaders, or 54.2, plus all of the truck and bus tires rejected, or 10.1, totalling 64.3 million.

The flow of tires from tire manufacturers to auto manufacturers is equal to the total shipments of new "original equipment" tires for cars, trucks, and buses combined, or 55.7 million (Diagram 1.2). The same flow is transmitted from auto manufacturers to auto retailers, and subsequently to consumers, as standard equipment on new cars. The flow of used tires from consumers to disposal is estimated to be 2 percent of passenger car replacement sales, or 4.0 million tires (Diagram 1.2); the flow of used tires to disposal as part of the equipment of vehicles disposed of is estimated to be 37.3 million (Diagram 1.2).

A material balance around the consumer block indicates that about 18.4 million tires per year are accumulated by the consumer. It is presumed that most of this accumulation represents the difference between cars produced and cars disposed of each year. Currently the United States is producing between two and three million cars a year more than it is disposing of, which would account for an annual increase in consumer tire inventory of between 10 and 15 million tires.

The total annual disposal figure derived from the model is 183.9 million; this may be compared with the approximate figure of 180 million referred to on page 1 of this report, and used generally throughout it.

Tire Manufacturers

There are 182 manufacturers of rubber tires, tubes and tire products in the United States, employing a total of about 92,700 people with annual sales of about $3.7 billion. Of these companies, 99 manufacture tires with tubes, with 70 of the 99 specializing in solid or semi-pneumatic tires for trucks, hand-trucks, bicycles, toys, and for a wide range of agricultural and industrial purposes.[8]

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[8] Poor's Register of Corporations, Directors, and Executives; United States and Canada. New York, Standard and Poor's Corporation, 1970.

The remaining 29 companies manufacture pneumatic tires, only a small portion of which (about 10 percent of all units) are produced for agricultural, industrial, or recreational equipment (Table 1.1).

In 1969 tire production totalled over 229 million units. Nearly all of these tires are utilized in the United States; only a small number (1 percent of total production) are exported.

Of the 29 companies producing pneumatic tires, 19 produce tires for cars, trucks, and buses; these companies are Armstrong Rubber Company, Cooper Tire and Rubber Company, Dayton Tire and Rubber Company, Denman Rubber Manufacturing Company, Dunlop Tire and Rubber Corporation, Firestone Tire and Rubber Company, Gates Rubber Company, General Tire and Rubber Company, B.F. Goodrich Company, Goodyear Tire and Rubber Company, Inland Rubber Corporation, Kelly-Springfield Tire Company, Lee Tire and Rubber Company, McCreary Tire and Rubber Company, Mohawk Rubber Company, OK Tire and Rubber Company, Schenvit Industries, Incorporated, Seiberling Tire and Rubber Company, and the Uniroyal Tire Company.

While the total production of new tires has increased steadily from year to year, sale of original equipment tires fluctuates with new car sales. The steady increase in total sales is accounted for by the sales of replacement tires for passenger cars. Thus, while original equipment tire sales were almost 10 percent lower in 1965 than 1969, because of a decline in new car sales, replacement sales increased nearly 40 percent (Table 1.2).

The passenger car tires, other than those supplied as original equipment to automobile manufacturers, were shipped to a variety of buyers (Table 1.3).[9]

Tire manufacturers affect the disposal of scrap tires in three areas: designing, marketing, and recycling. Design factors include size, shape, structural characteristics, materials content, and uniformity. Size (set primarily by the automobile manufacturer) is a factor because theoretically large-diameter tires are capable of wearing longer than smaller tires for two reasons: first, they permit less heat build-up, and second, they require fewer revolutions per mile. Longer wear mitigates the disposal problem by reducing the total number of carcasses discarded in any given year.

Tire shape is a disposal factor insofar as extra-wide carcasses add to the total volume of waste per tire, without adding to the tire's mileage. Several tire engineers reported that extra-wide tires also wear out faster than conventional tires of equivalent specifications because they are more subject to flexing.

Structural characteristics determine the suitability of a tire for retreading. In general, cheaply made tires are less suitable for recapping and more likely to end up on the scrap heap than tires with high-quality carcasses. Aside from quality, however, some types of tires are more suitable for retreading than others. The new glass-belted tires, for example, have

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[9] Personal communications. R.E. Wilkins, Firestone Tire and Rubber Company, to T. Schell, International Research and Technology Corporation, July 16, 1970.

TABLE 1.1

TOTAL UNITED STATES OUTPUT OF PNEUMATIC TIRES

Tire Type	Percent Output
Passenger Car	77.7
Truck and bus	10.9
Bicycle	5.0
Industrial	3.0
Tractors	2.6
Aircraft	.4
Motorcycle	.1

TABLE 1.2

TOTAL TIRE SHIPMENTS
(thousands)

Year	Passenger Car Original Equipment	Passenger Car Replacement	Truck and Bus Original Equipment	Truck and Bus Replacement
1965	51,413	94,893	6,943	12,819
1966	47,362	101,812	7,401	14,613
1967	40,827	108,499	6,873	14,418
1968	49,873	121,088	8,488	16,257
1969	46,206	129,310	9,497	17,340

Reference 9

TABLE 1.3

TIRE SHIPMENTS

Year	No. of Replacement Tires Mfg. & Shipped	% to Oil Companies (Service Stations)	% to Retailers	% to Wholesalers	% to Chain Stores & Mail Order Houses	% to Tire Co. Owned Stores	% to Dept. Stores	% to Others
1965	94,893,000	25	27	9	20	10	6	2
1966	101,812,000	23	29	11	21	10	4	2
1967	108,499,000	21	29	13	21	10	4	2
1968	121,088,000	19	32	14	19	10	4	2
1969	129,310,000	17	33	16	18	10	4	2

been somewhat harder to retread than rayon or nylon cord bias-ply tires. This is due partly to slight irregularities in the contours of some of the new tires which have caused difficulties in the buffing process that precedes the application of new tread. Manufacturers of new tires could eliminate the latter difficulty by improving the quality control of belted tires.

This will be of crucial importance to the retreading industry, since the construction of new tires is shifting rapidly from conventional to fiber glass-belted tires. The trend is expected to continue (Table 1.4).[11]

Structural characteristics also affect wear, insofar as some types of tires run considerably cooler than others. Radial tires, which are subject to much less flexing than other types, are expected to give better mileage than bias-ply, at least for some cars. While these tires also cost more to the consumer (the cost-per-mile ratios are not necessarily better than those of much cheaper tires), they have the virtue of sharply reducing the frequency with which carcasses must be discarded. It has been estimated that a steel-belted radial tire, if suitably retreaded several times, might have a carcass life of 100,000 miles.[7]

Some of the materials used in tire fabrication interfere with disposal or reuse. Steel belts and studs, for example, render tires unusable by rubber reclaimers.

Tires differ substantially from one another in composition. Tables 1.5 and 1.6 give approximate specifications of a typical 1968 passenger car tire size 7.75-14.

The most important impact of materials changes on recycling is the manufacturers' continuing de-emphasis of reclaimed rubber. If technological and economic considerations permitted the incorporation of large quantities of this material in new tires, the disposal problem could be largely solved through direct recycling. At present, however, such incorporation does not seem feasible. To a small extent, of course, the chances of developing a means of direct recycling in the long-range future will be affected by the tire manufacturers' present priorities for research and development.

A lack of uniformity in tire sizes produced by the manufacturers also has an effect on tire reuse. Uncommon sizes are less suitable for retreading, because retreading equipment must fit closely to the carcass to be retreaded. Odd-sized tires are discarded by some retreaders because they do not accumulate in sufficient numbers to justify stocking the additional molds necessary to fit them. The proliferation of tire sizes also contributes to carelessness in the fitting of tires to cars, since any car can use tires of several different sizes. Sometimes tires of two, three, or four different sizes are mounted on the same car. Whether such practices are caused by the unavailability of matching sizes or by the carelessness of the purchaser in replacing individual tires, the result is likely to be excessive tire wear. Responsibility for the

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[11] "Technology Revolution in 70's to Fill Rubber's Pot of Gold". Rubber World vol.161, no. 5, Feb., 1970.

TABLE 1.4

TIRE SALES BY TYPE*

Year	Radial	Bias-ply	Belted-bias
1968	1.6	92.4	6.0
1969	2.1	64.9	31.0
1970	2.7	32.3	65.0
1971	3.4	26.6	70.0

*Percent of sales.

TABLE 1.5[7]

TIRE CONSTITUENTS BY WEIGHT
(in pounds)

Tire Constituents	Weight
Fabric	2.5
Bead Wire	1.0
Rubber Compound	21.5
TOTAL	25.1

TABLE 1.6[7]

RUBBER COMPOUND CONTENT

Material	% of Total	Weight in lbs.
Rubber Polymer (including reclaim)	47	10.1
Carbon Black	30	6.5
Oil	18	3.9
Chemicals	3	.6
Zinc Oxide	2	.4
TOTAL	100	21.5

proliferation of tire sizes is shared by the automobile manufacturers. The present selection of automobiles, however, would permit more standardization of size and other specifications than is presently the case, and such standardization would reduce the number of tires discarded by the retreading industry. It is significant, for example, that although scores of different passenger car sizes are produced, 10 of these sizes account for 85 percent of all sales.[12]

Major tire manufacturers, in marketing their product, affect the disposal of scrap tires through their influence on the buying habits of consumers, and on the disposal practices of franchised retail dealers.

Here, as in the area of tire design, the policies of the manufacturers are relevant primarily to tire wear and retreadability. Advertising can influence the sales of longer wearing or more retreadable tires, and recommendations by the manufacturers can influence the extent to which owners maintain their tires so as to maximize durability.

Tire manufacturers are involved in another type of recycling activity-the development of new processes intended to recover chemical constituents of scrap rubber for commercial resale (these are discussed in a subsequent section on destructive distillation, carbonization and hydrogenization). These processes are in various stages of research and development; their potential for reducing rubber waste has not yet been realized.

Automobile Manufacturers

The four major domestic automobile manufacturers--American Motors, Chrysler Corporation, Ford Motor Company and General Motors constitute the largest bulk purchasers of new tires in the United States, with plants located in 40 cities. The following table sets forth the number of tires purchased for use as original equipment on passenger cars, trucks, and buses by the American automobile manufacturing industry, and the percentage of total new tire sales that are represented by the tires furnished as original equipment on these vehicles.[12]

The automobile manufacturer and importer sell new automobiles, both foreign and domestic, through a network of 32,898 franchised dealers, 2,389 of which sell imported cars exclusively.

Automobile manufacturers play a leading role in tire design, which, in turn, affects tire wear and waste formation. Automobile designers determine size, vehicle weight, suspension characteristics and, to a great degree, operating speeds.

The two aspects of automobile engineering that affect tire waste markedly are performance and suspension characteristics. Increased emphasis on high performance, in terms of acceleration and cruising speeds, increases heat buildup in tires and reduces the degree to which reclaimed rubber can be used in new tire construction. Automobile suspensions have a controlling influence on the air pressure that is appropriate for the tires used with them. High air pressure reduces tire flexing and by doing so reduces tread wear directly, as well as tire failure resulting form heat buildup. High pressure, however, also reduces the damping effect of the

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[12] Zielasko, E.H., ed. Tire and Car Service Directory Almanac. Akron, Ohio, Modern Tire Dealer, 1970.

TABLE 1.7

ORIGINAL EQUIPMENT DISTRIBUTION

Year	Total U.S. Tire Production (000)	No. Supplied as Original Equipment (000)	Original Equipment as Percentage of Total Tires Manufactured
Passenger Cars			
1965	147,268	51,413	35%
1966	154,516	47,362	31%
1967	141,896	40,827	29%
1968	177,408	49,873	28%
1969	180,616	46,206	26%
Trucks and Buses			
1965	20,475	6,943	34%
1966	22,872	7,401	32%
1967	21,165	6,873	32%
1968	25,533	8,488	33%
1969	27,211	9,497	35%

SOURCE: See footnote 12.

tires on shock and vibration transmitted from the road surface to the suspension system. Automobile design in the United States has relied upon tire characteristics to absorb as much vibration as possible. As a result, automobile manufacturers have tended to recommend the lower-range tire pressures that promote flexing.

The relationship of the automobile manufacturers to the tire manufacturer dominates market-wide changes in tire design. For example, as of November 1970, during a year of transition from bias-ply to belted-bias, 88 percent of the tires being supplied as original equipment by automobile manufacturers were of the new belted-bias design, while the tires being shipped by tire manufacturers for distribution through the replacement market were still only between 30 percent and 35 percent belted-bias.[13]

Tire Retailers

Retail tire sales are divided among a variety of businesses. The principal outlets are gasoline service stations and independent tire dealers. Together, they account for about two-thirds of all retail sales. The remaining third is accounted for by manufacturers' outlets, department stores, auto supply stores, new car dealers, and garages. In a survey of 1,777 car owners carried out during 1966, new replacement tires (excluding retreads) were purchased during a 4-month period from a number of outlets (Tables 1.8 and 1.9).[14]

Of those tires purchased at gasoline service stations, more than 50 percent were obtained at the outlets of five companies.[14] The remaining 50 percent were sold at outlets of more than 14 other oil companies.

There are about 216,000 gasoline service stations in the United States, and about 29,000 tire, battery, and accessory dealers. The total employment of those two categories alone totals more than 1 million.[2]

In addition, an indeterminate number of employees of department stores, auto dealerships, etc., are involved in retail sales of tires. Thus, even allowing for a large number of employees of service stations and tire dealer employees who are not directly involved, it is reasonable to assume that close to a million people handle retail sales of automobile tires at least occasionally, if not regularly. This number is significant because the advice of the retail salesman to the consumer has a significant bearing on purchasing patterns, maintenance, and disposal, and through them, tire waste. The bulk of these sales is handled by about 200,000 people; at least this number would have to be reached by an educational program designed to reach the majority of consumers through personal contact.

Tire retailers affect the disposal of scrap tires through (1) their influence on consumer preferences; (2) their influence on tire maintenance; (3) their handling of scrap tires during the replacement process; (4) their disposition of scrap tires left by customers.

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[13] Personal communication. W. A. Terall, Firestone Tire and Rubber Company to E. Ayres, International Research and Technology Corporation, Nov. 5, 1970.

[14] A study of the consumer market for new replacement tires for passenger cars. Study conducted by Market Facts, Inc., Washington, D. C., U.S. News and World Report, 1967.

TABLE 1.8

DISTRIBUTION OF TIRE SALES

Type of Outlet	Percentage Purchased
Gasoline Service Station	35.3%
Tire Store or Dealer	32.0%
Chain Department Store	17.0%
Other Department Store	1.9%
Automotive Supply Store	4.0%
New Car Dealer	4.6%
Discount House	2.3%
Garage	1.9%
Other	5.5%
TOTAL	104.5%*

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*Figures total more than 100.0 percent because some buyers bought at more than one type of outlet.

TABLE 1.9

TIRE SALES BY MAJOR OIL COMPANIES

Companies	Sales Percentage
Standard of Indiana	12.4%
Texaco	10.9%
Mobil Oil	10.3%
Standard of New Jersey	8.6%
Shell	8.6%

The possibilities for dealer influence on tire grade preferences are indicated by a study of new-tire buyers. This indicates that such buyers are far less constrained by budgetary considerations than the average consumer. According to this study, some 60 percent of new tire buyers own two or more cars, and 14 percent own three or more. The average family income of all new tire buyers was $10,700 in 1966, and is certain to be even higher at present.[14]

Tire dealers can also affect waste through their communications with customers regarding proper tire maintenance. There are several areas in which maintenance can make a difference in tire wear or ultimate retreadability. These include air-pressure recommendations (underinflated tires wear out more rapidly), advice about wheel balancing and alignment (poor balance or alignment also increases wear), reminders about periodic rotating (unrotated tires wear unevenly), and warnings about the danger of allowing a tire to wear down to less than 2/32-inch tread depth (bald tires cannot be retreaded).

The percentage of tires scrapped in unretreadable condition is affected by the manner in which old tires are removed from their wheels by new tire dealers. Retreaders report that many tires suffer bead damage during the removal process, which renders them unusable. Greater care in tire removal would sufficiently increase the supply of usable carcasses to facilitate significant reductions in the cost of sorting and collecting, and hence in the number of tires collected by retreaders.

The most important aspect of retailer involvement in the disposal process is the method by which he disposes of the used tires left behind by purchasers of new tires. If he is a small-volume retailer, his accumulation of used tires will be too small to warrant collection by a retreader. He will attempt to dispose of them a few at a time, through regular municipal trash collections. A larger retailer will expect to sell all his used tires to a retreader and to be paid at a rate of $0.75 to $1.50 for each retreadable tire.[4]

Consumers

In 1968, 105,400,000 licensed U.S. motor vehicle operators drove 73,400,000 registered passenger cars more than 502,300,000 miles. In the maintenance and replacement of their tires, the operators purchased approximately 121,088,000 new replacement tires and 45.5 million retreaded tires.

Consumer preferences (and resulting purchases) have a direct bearing on the number of scrap tires generated, since longer-lasting tires necessitate fewer replacements in any given year. Because less than one-third of all retail sales are premium-line tires, a change in the buying habits of the majority of tire users could bring about a significant reduction in the total output of scrap tires.

This is particularly true for the purchasers of second- and third-line tires who account for some 20 percent of retail sales. Tire dealers who encourage or discourage the purchase of "cheap" tires also have an effect on the percentage of tires discarded in retreadable condition, since better quality new tires produce better quality carcasses for retreading. The current potential for significant reductions of waste through changes in retail sales patterns are indicated by a survey of tire users and distribution of sales; these results are corroborated by a different survey showing the prices paid for new 1969 tires of various grades (Tables 1.10 and 1.11).[14]

After his purchase of the tire, the consumer's subsequent maintenance of it has a marked effect on the mileage he will receive from it. Surveys have indicated that in cars for which 24 pounds per square inch is the minimum recommended pressure, 28.4 percent have one or more tires inflated to 20 psi or less with pressures ranging as low as 12 psi.[2] The effect of underinflated or overinflated tires is to distort the shape of the tire. Underinflation causes the tire to buckle in the center so that the side treads receive excessive use.

Overinflation causes the center of the tire to swell, exposing it to excessive wear. The extent to which improper pressure reduces tire life depends on average driving speed, climate, and typical pavement surface. An estimate based on test runs of many brands and sizes of tires carried out by a major manufacturer[15] relates the effect of underinflation to tire life according to the following equation:

$$\text{Percent of Life at 24 PSI} = \frac{\text{inflation}}{0.401\ (\text{inflation}) + 14.338}$$

Table 1.12 shows the life at various pressures, as derived from this equation.

Each purchase of a replacement tire means the discard of a worn tire. According to interviews with major tire wholesalers and retailers, consumers leave 96 to 98 percent of the discarded tires with the retailer from whom the replacement is purchased. There is, however, an indeterminate proportion of the remaining discards which is disposed of along with segregated or unsegregated household or corporate waste, and another percentage which is dumped as litter or brought directly to auto junk dealers or retreaders.

Retreaders

Approximately 7,000 tire retreading plants recapped an estimated 46.5 million truck and passenger car tires in 1969.[3] The number of passenger car retreads has been rather constant in recent years, although the number of truck tires recapped has been growing steadily.

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[15] Personal communication. W. D. Dobie, U.S. Rubber Tire Company, to E. Ayres, International Research and Technology Corporation, Aug. 21, 1969.

TABLE 1.10

SALES BY GRADE OF TIRE PURCHASED

Grade of Tire	Sales Percentage
Premium	32%
First Line	45%
Second Line	15%
Third Line	6%
Other	7%

TABLE 1.11

SALES BY TIRE PRICE CATEGORY

Tire Price Category	Sales Percentage
$32.50 and up	26.0%
$27.50 to $32.49	29.9%
$22.50 to $27.49	26.8%
$17.50 to $22.49	11.0%
$12.50 to $17.49	6.3%

TABLE 1.12

EFFECT OF INFLATION ON TIRE LIFE

Inflation PSI	Percent of Life at 24 PSI
8	45.5
10	54.4
12	62.5
14	70.1
16	77.0
18	83.3
20	89.4
22	95.1
24	100.0

$$\text{Percent of life at 24 PSI} = \frac{\text{inflation}}{0.401\ (\text{inflation}) + 14.338}$$

TABLE 1.13

PROJECTION OF RETREADED TIRES
(millions of tires)

Year	Passenger Car Tires	Truck Tires
1965	36.0	7.6
1966	35.3	8.0
1967	34.5	9.3
1968	35.8	9.7
1969	36.5	10.0

The overall trend toward annual increased production of retreads is further confirmed by statistics showing the amount of tread rubber manufactured and shipped to tire retreaders. The 1963 output of 518.4 million pounds increased to a level of 562.9 million pounds in 1967.[6]

Approximately 98 percent of all purchasers of car replacement tires for passenger cars leave their worn tires with the establishment installing the tire. In the process of collecting these casings, the retreaders evaluate approximately 60 percent of all discarded tires, and find between 25 percent and 50 percent of these to be retreadable.[7] The retreads are then sold, and constitute approximately 22 percent of the replacement tire sales for passenger cars.

The retreader typically buys, unsorted, the entire accumulation of discarded tires left with major retailers by their customers, at a price that results in a cost of approximately $0.75 for each usable tire. When demand for retreads exceeds the supply he is able to obtain from local retailers, he will buy retreadable carcasses from a carcass wholesaler or tire broker for $1.25 to $3.00, depending on the size, model, and condition.[7]

The process of sorting results in rejection of from 50 percent to 75 percent of the casings due to defects. The proportion refected seems to depend primarily on the quality standards of the retreader. When major tire manufacturers retread under contract to major mail order houses, their reject rates range between 70 percent and 80 percent.

The unretreadable tires are disposed of in one of several ways. To the extent that the reclaiming industry is able to absorb scrap tires, they are shipped by retreaders to reclaimers. The rubber reclaiming industry used 141.3 million pounds of worn tires or approximately 7 million tires as raw material in 1968.[6] This accounted for approximately 4 percent of the used tires that we estimate were discarded during that year. Most retreaders within 200 to 300 miles of reclaiming plants pay handling and transportation charges to the reclaimers. Some reclaimers are paying $6 to $10 a ton for tires delivered to them pursuant to schedules; others pay nothing. The need to dispose of scrap tires is so urgent, however, that the few retreaders from more remote areas who are able to make the necessary arrangements, dispose of tires by paying all handling charges as well as freight charges of $12 a ton to any reclaimer who will accept their tires, free of cost, at his plant.[7]

The overwhelming bulk of the retreaders' unrecappable tires, however, is dumped. A retreader with access to a municipal open dump willing to accept his tires often pays $7 to $10 a ton to the municipality for the privilege of dumping his scrap tires, in addition to his handling and hauling costs. Sanitary landfill operations sometime set aside special areas for tire disposal. Charges to retreaders for use of such sites can be as high as $2 per cubic year. Retreaders report that they either pay contractors to haul away tires, or haul them themselves. Costs range from $0.05 to $0.20 per passenger car tire and $0.75 to $0.80 per truck tire. Either the dumping is done through purchase of exclusive dumping rights on private dump sites or it is done clandestinely on private land.

The retreading process starts with selection of a retreadable casing. The casing is then placed on a buffing machine that, following a size template, grinds off the remaining old tread so as to leave the carcass the exact size and contour to fit a specific matrix or mold. The tire is then built up by the application of a bonding cement and tread rubber. The carcass is placed in the matrix for curing where, by a combination of heat and pressure, the new tread is vulcanized to the carcass.

Passenger car retreads are purchased by consumers through channels shown in Table 1.14.

The flows of truck and bus tires to and from the retreader are substantically different from those of passenger car tires. It is estimated that nearly 100 percent of the retreading of truck and bus tires is accomplished in custom operations.[4] The owner of such tires brings them directly to the retreader, demands and receives 72-hour service, and then reuses the tires on his own vehicles. The consequent availability on the retail market of retreaded truck and bus tires is very low, since for the most part, only nonretreadable casings are discarded. The retreading of these tires is accomplished by 70 percent of the total 7,000 retreaders, 5 percent of whom retread turck and bus tires exclusively.

Theoretically, the retreading industry could reduce the number of tires discarded each year by improving the durability of the bond between carcass and tread. The retreaders, however, are dependent upon the rubber industry for the development of adhesives, for quality control of size variation, and for control over tire carcass specifications. It is not likely that the retreaders on their own will be able to produce marked improvements on bonding. A more promising opportunity for the retreaders to reduce scrap tire discards lies in the possibility of collecting and inspecting all the used tires left with retailers by consumers instead of only a majority of them. The actual figure for the total number of tires examined by retreaders is doubtful. We have calculated that the tire retreading industry, including both carcass dealers and retreaders, examined a total of about 104.3 million passenger car tires. Assuming that one passenger car tire was left with retailers for every new or retread replacement tire sold in 1968, 161.8 million tires were available for examination that year. If collection costs had made it economically feasible to do so, then 35 percent of the 57.5 million unexamined tires, or about another 20 million retreadable tires, could have been diverted from the waste stream by being retreaded.

Disposal

Rubber product waste amounted to more than 10 billion pounds in 1968, of which 6 billion pounds consisted of scrap tires and tubes. Of this 6 billion, a net of about 1.7 billion pounds were recycled, mostly to retreaders but partly to reclaimers and tire splitters. Per capita rubber waste before recycle ranges from a low of 40 pounds per year in Hawaii, to 72 pounds per year in Wyoming.[16] The before-recycle national average is about 51 pounds, equivalent to roughly one tire and 20 pounds of miscellaneous rubber waste per year, or slightly over 2 pounds per capita.[16]

By excluding dust and gas from tire wear, most tire waste consists of

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[16] Braner, H. M. An Analysis of the Domestic Retreading Industry. Englewood, N.J., Ranno Printing Company, 1965.

TABLE 1.14

DISTRIBUTION OF PASSENGER CAR RETREADS

Source of Purchase	Percent of Passenger Retreads Purchased From Given Source
Directly from retreader	53%
From tire dealers	16%
From service stations	26%
From other retailers	5%

whole discarded tires from passenger cars, buses, and trucks. There are three rubber reuse markets for used tires: retreading, reclaiming, and splitting. Reclaiming uses 3 percent of the scrap tires and splitting uses less than 1 percent. Both have only limited markets for their products. The retreading industry accounts for nearly a quarter of replacement sales and could be expanded to account for much more. At present, more than half of all used tires are discarded by retreaders.

Tires discarded by consumers or rejected by reuse industries are not the only source of tire waste. Reuse industries--particularly retreaders and reclaimers--also generate about 20 million pounds of process waste per year.[16]

By excluding process waste from retreading or new tire production, three major sources of scrap tire waste are obtained. These are: (1) tires manufactured in the United States for passenger cars, trucks, and buses and used once; (2) imported tires used once; (3) discarded retreads. We estimate 180 million are discarded.* Some of these tires were burned in open fires or consumed by municipal incinerators, but the vast majority are taken to authorized disposal sites or simply abandoned at the convenience of the retreaders who collected them or the tire retailers who accumulated them. This remains the general pattern of scrap tire disposal in 1970.

CHAPTER 2

DECISION POINTS

In order to determine what kinds of incentives are likely to change the patterns of tire manufacturing, distribution, and use affecting the rate and method of tire discard, we have prepared a series of decision charts. These charts designate the alternative routes and the criteria that govern the direction of each major step in the progress of the tires from fabrication to disposal site.

Figure 2.1 shows the decision chart for the tire manufacturer who decides whether, and in what proportion, to use polyester, fiber glass, rayon cord, nylon cord, steel cord, new natural rubber, new synthetic rubber (and of what type and compound) and reclaimed rubber. In making his selection, the tire manufacturer is guided by such factors as abrasion resistance, heat resistance,

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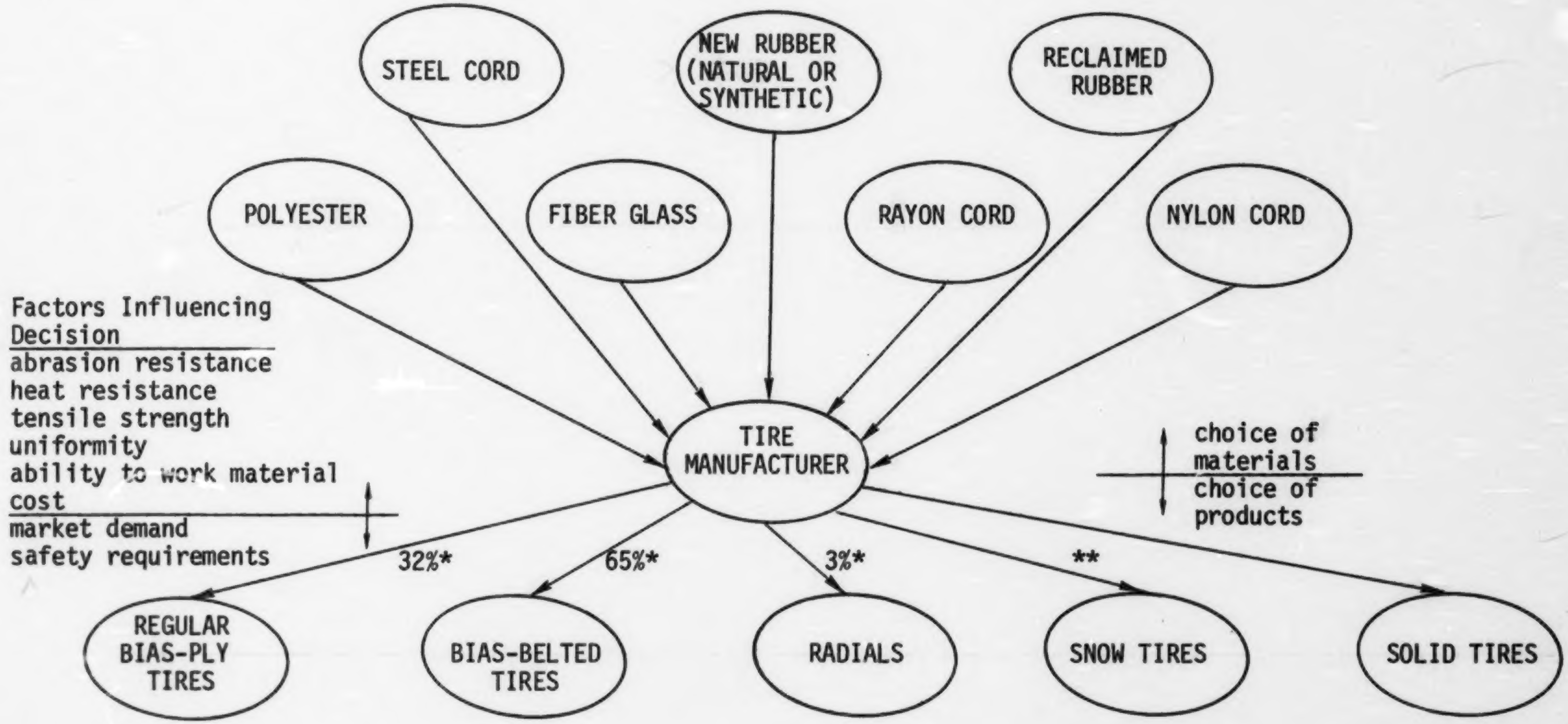
*See footnote on p. 1.

FIGURE 2.1

DECISION CHART FOR THE TIRE MANUFACTURER


STEEL CORD
NEW RUBBER (NATURAL OR SYNTHETIC)
RECLAIMED RUBBER
POLYESTER
FIBER GLASS
RAYON CORD
NYLON CORD
Factors Influencing Decision
abrasion resistance
heat resistance
tensile strength
uniformity
ability to work material
cost
market demand
safety requirements
TIRE MANUFACTURER
choice of materials
choice of products
32%*
65%*
3%*
**
REGULAR BIAS-PLY TIRES
BIAS-BELTED TIRES
RADIALS
SNOW TIRES
SOLID TIRES

*Percent of pneumatic passenger car tires only.

**Snow tires included in percentages for other pneumatic types.

tensile strength, uniformity, the ease with which these materials can be worked and their costs. He also must determine whether to make them into regular 2 or 4 bias-ply tires, bias-belted tires, radial tires, snow tires or solid tires. He makes his selection from these alternatives primarily on the basis of market demand, but his decision is tempered both by considerations of the safety requirements imposed by a given market-dictated use and by the availability of necessary materials. (U.S. tire manufacturers in 1970 were anxious to produce a larger number of steel-belted radial tires, but were unable to do so because of the lack of domestic suppliers of the steel wire needed for construction of such tires. Increased steel-belted radial production had to await completion of a steel cord plant. Similarly, although the demand for polyester and fiber glass bias-belted tires was considered to be the dominant market force in 1970, only 30 percent of the replacement tire sales were of this type. This was due to shortages in capacity to produce the necessary materials or to fabricate the bias-belted design.)

Figure 2.2 shows three alternatives facing the consumer when he selects the type and grade of tire that he will purchase from the retailer. He has to decide whether he wants relatively inexpensive retreads, inexpensive or expensive 2 or 4 bias-ply tires, or more expensive radials or bias-belted tires. He may choose snow tires with or without steel studs, or he may choose a tire with a particular styling characteristic, a white sidewall, a red stripe, or wide oval design.

The consumer will also be guided by considerations of cost, safety, durability, brand and style as influenced by advertising, habit and, at least with respect to steel studded snow tires, state regulation.

Figure 2.3 shows the alternatives for the consumer in deciding where to buy replacement tires. He will be governed by considerations of cost, convenience (including time required), and habit.

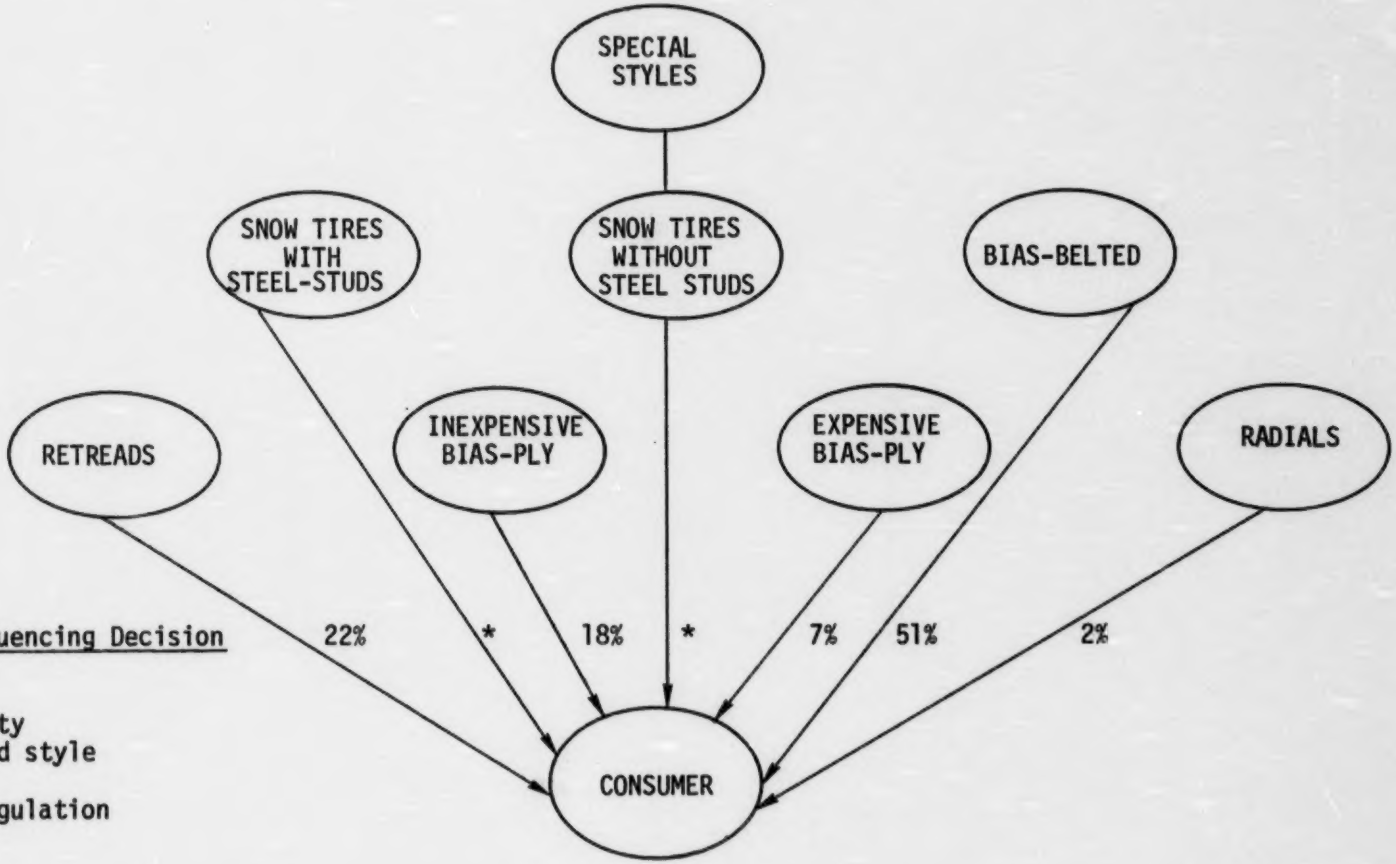
Figure 2.3 also shows the choices confronting the consumer when he decides what to do with his worn tires. The overriding consideration in this choice is convenience. Due to the difficulty in removing a tire from a rim, the consumer is not likely to replace the tires himself. He will tend to leave his used tire with the retailer from whom he purchases his replacement tire, whether it is a new tire or a retread. If the worn tire does not have a puncture or defect, other than its lack of tread, the consumer might elect to keep the tire as an emergency spare. On the other hand, a cost incentive such as a retailer's offer of reduced new tire price for customers turning in retreadable casings would influence the decision whether to leave the tire with the retailer. A municipal ordinance prohibiting disposal of tires through municipal facilities would also reinforce such a decision.

Large fleet owners tend to deal directly with tire retreaders or carcass dealers; they are guided by economic considerations.

Figure 2.4 shows the alternatives confronting the tire retreader who must decide where to obtain his retreading stock and where to dispose of his unretreadable carcasses. The retreader's sources of tire carcasses include his own customers, tire dealers, filling stations, department stores and mail order houses, and tire brokers. The criteria affecting his choice are cost, convenience, and supply.

FIGURE 2.2

DECISION CHART FOR THE CONSUMER
(TYPE OF TIRE: PASSENGER CAR)


SPECIAL STYLES
SNOW TIRES WITH STEEL-STUDS
SNOW TIRES WITHOUT STEEL STUDS
BIAS-BELTED
RETREADS
INEXPENSIVE BIAS-PLY
EXPENSIVE BIAS-PLY
RADIALS
22%
*
18%
*
7%
51%
2%
CONSUMER

Factors Influencing Decision
- cost
- safety
- durability
- brand and style
- habit
- state regulation

*Snow tires and special styles included in figures for other types.

FIGURE 2.3

DECISION CHART FOR THE CONSUMER
(PLACE OF PURCHASE AND DISPOSAL)

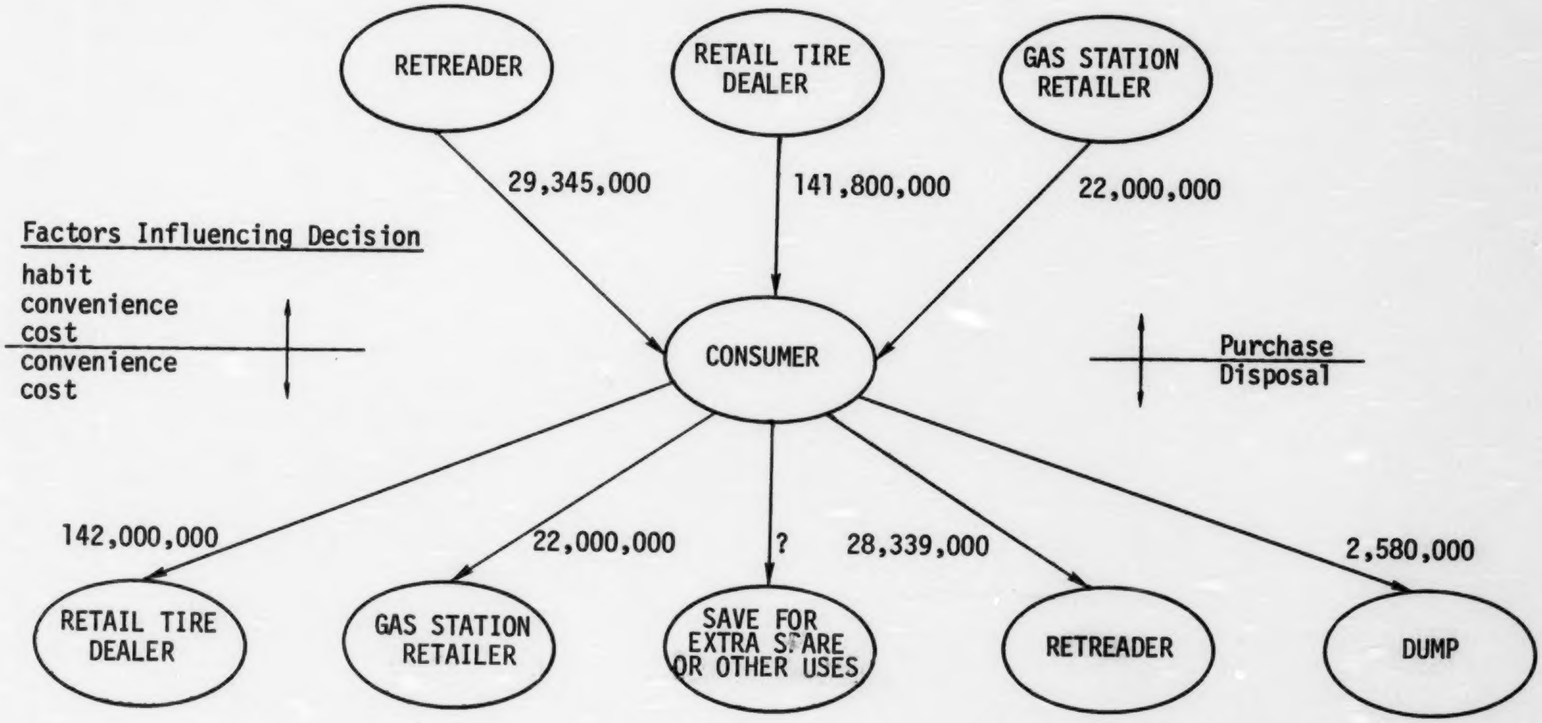
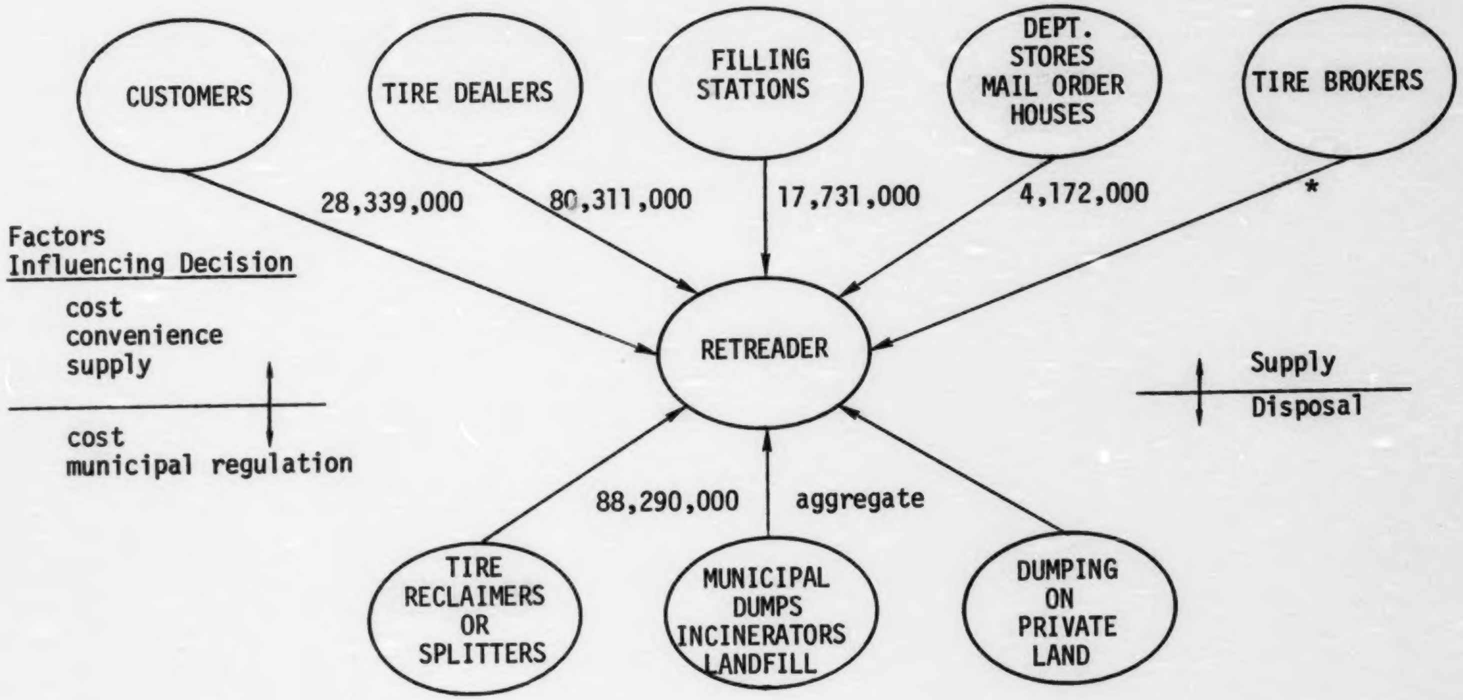

RETREADER
RETAIL TIRE DEALER
GAS STATION RETAILER
29,345,000
141,800,000
22,000,000
Factors Influencing Decision
habit
convenience
cost
convenience
cost
CONSUMER
Purchase
Disposal
142,000,000
22,000,000
?
28,339,000
2,580,000
RETAIL TIRE DEALER
GAS STATION RETAILER
SAVE FOR EXTRA SPARE OR OTHER USES
RETREADER
DUMP

FIGURE 2.4

DECISION CHART FOR THE RETREADER
(CARCASS SUPPLY AND DISPOSAL)


CUSTOMERS
TIRE DEALERS
FILLING STATIONS
DEPT. STORES MAIL ORDER HOUSES
TIRE BROKERS
28,339,000
80,311,000
17,731,000
4,172,000
*
Factors
Influencing Decision
cost
convenience
supply
cost
municipal regulation
RETREADER
Supply
Disposal
88,290,000
aggregate
TIRE RECLAIMERS OR SPLITTERS
MUNICIPAL DUMPS INCINERATORS LANDFILL
DUMPING ON PRIVATE LAND

*Broker shipments included in figures for tire dealers, filling stations, department stores, etc.

In deciding where to dispose of carcasses, the retreader chooses among tire reclaimers or splitters, municipal dumps, incinerators, or landfill, or dumping on private land either directly or through a contractor. His decision is based on cost but may be affected by municipal regulation.

CHAPTER 3

END USES FOR USED RUBBER TIRES

General

The following material sets forth a number of uses to which tires may be put once original tread has worn off. Some of the modes of employment described below fall within traditional concepts of reuse or recycling, in which the used tire can reenter the economy in the form of raw materials for the construction of a new tire. Other uses, while not recycling uses, do provide an opportunity to employ tires in an economically productive way. Still other processes which we have listed here as "uses" might more properly be called "means of disposition". With respect to these, our intention has been to describe forms of tire disposal that would prevent further accumulations of tires as an obstruction in the solid waste stream without causing any other form of environmental deterioration.

Power Production

Pound for pound, the BTU content of used tires is comparable to that of coal. Pilot installations in England have used tires as fuel in specially designed burners to generate electricity.

The market for power production in the United States could absorb the entire annual output of tires in the form of fuel for steam plants, without having an appreciable impact on the demand for coal. Whereas the total quantity of fossil fuel consumed in 1967 was 17,000 x 10 BTU,[17] the quantity of scrap tire rubber produced in the same year, assuming an average of 13,000

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[17] Morrison, W. E., and C. L. Readling. "An Energy Model for the United States, Featuring Energy Balances for the Years 1947 to 1965 and Projections and Forecasts to the Years 1980 and 2000". U.S. Bureau of Mines Information Circular 8384. Washington, D.C., U.S. Government Printing Office, 1968.

BTU/lb,[18] was about 78×10^{12} BTU, the equivalent of less than half of 1 percent of the total fossil fuel consumption. This difference in scale accounts for the principal difficulty in utilizing used tires to generate power. Even the largest cities do not discard enough tires to sustain a power plant large enough to be commercially feasible. A tire burning plant would have to operate as a supplementary installation to augment the output of a larger plant, possibly as a peak load auxiliary.

While there is general agreement in the rubber industry about the potential value of scrap rubber for fuel, there is some disagreement about actual costs. The economics of this end use would vary depending on the type of furnace used, the size of the operation, and the availability of tires.

The cost of a furnace is a function not only of its capacity, but of the extent and effectiveness of its emissions control equipment and the efficiency of its incineration process. Heated rubber may melt and form compacted masses which are slow and difficult to burn, consequently the furnace grates must be carefully designed. Because burning rubber generates smoke which is more noxious and acrid than that of most other common varieties of solid waste, the stack controls must be particularly effective.

Due to the special combustion properties of rubber, scrap tire furnaces are likely to be less efficient than coal furnaces. A conservative estimate is that a tire furnace of moderate size would generate steam in a water tube boiler at an overall efficiency of 30 percent--less than half that of a comparable coal furnace.[18] Even at this efficiency, however, tires may be competitive with conventional fuels. A British firm, the Watts Tyre and Rubber Company, operates a plant which consumes over 700 tires per hour, generating 3,500 pounds of steam per hour with savings of about $110 per day over the cost of coal, which is the cheapest available conventional fuel.[18] These savings are maximized, of course, by the fact that the Watts Company has its own supply of scrap tires and does not need to transport them from outside sources. Collection and handling cost could make the relative cost of using scrap tires as a fuel considerably higher than coal.

Goodyear estimates that the total cost of generating power from tires would average $0.49 per million BTU exclusive of collection costs, compared to $0.35 per milliom BTU of coal. These costs include, in addition to the fuel itself, amortization costs of capital equipment (three times as high for tires as for coal) and operating costs of storage, handling, preparation, and emissions control (more than 50 percent higher for tires than for coal). On the other hand, the total cost of tires is still considerably less than that of fuels other than coal, such as gas ($0.60 per million BTU) or oil; ($0.75 per million BTU).

The environmental impact of using rubber tires for fuel is no different from that of using coal of good quality, providing the requisite afterburners and particulate control equipment are used. In either case, the need for effective stack controls poses a problem for which existing solutions are compromises at best. The sulfur content of tires is between 1 percent and 2 percent. While this is lower than that of most coal, it is above the 1 percent standard increasingly required in metropolitan areas. Power production from tire-fueled plants, like power production from other fossil fuel combustion, would require better sulfur dioxide controls than those now commercially available, but within the state-of-the-art expected to be achievable within the next 5 years.

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[18] Goodyear Tire and Rubber Company. Unpublished data, Oct. 1970.

Destructive Distillation, Carbon Black Recovery, and Hydrogenization

Although present rubber "reclaiming processes" do not yield rubber of a quality comparable to new rubber, it is possible, by more complex processes, to recover some of the chemical constituents of tires. Such processes might permit the recycling of the chemical components into new synthetic rubber. At least three different approaches to constituent-recovery have been attempted, none of which can be fully evaluated until the completion of the developmental work which is presently underway. These approaches are destructive distillation, carbonization,* and hydrogenization. Distructive distillation and carbonization are forms of pyrolysis--a controlled oxygenless heating process that causes chemical compounds to decompose (giving off their volatile components and leaving a carbon residue); it is very similar to the coking process. Hydrogenization, on the other hand, is a process of chemical synthesis. It entails the addition of hydrogen--the element which is removed from oil to make synthetic rubber--in order to convert the rubber to chemicals from which new rubber can be synthesized. Hydrogenization and destructive distillation are both being developed by the private sector with a view to extracting a variety of salable constituents from tires. Carbonization is being developed with a view to extracting one major constituent--carbon black.

The principal (ultimate) constituents of tires are carbon (83%), hydrogen (7%), and ash (6%). There are also small quantities of nitrogen, oxygen, and sulfur. In pyrolysis, these constituents are yielded in the form of chemically complex oils and gases and a solid residue. The proportions of these yields vary according to the temperatures used in the process. Thus, at 500 degrees C, large quantities of liquid are yielded; at 900 degrees C, there is less liquid but more gas and residue. The difference between destructive distillation in general, and carbonization in particular, is, therefore, primarily one of temperature. The major product of high temperature carbonization is carbon black, a component that makes up one-third to one-fourth of the synthetic rubber from which tires are made. Destructive distillation yields about 50 products. The gases include methane, propane, and butane; the oils consist mostly of olefins, aromatics, and napthenes. This process also leaves a dry friable residue consisting mostly of carbon.

In an investigation of destructive distillation conducted jointly by Firestone and the Bureau of Mines, the amount of residue varied, depending upon the temperature of the process, from a high of 1,172 pounds per ton of tires treated to a low of 730 pounds per ton.[19] The residue has approximately the heating value of the tires (more than 13,000 BTU per pound) and would be a high quality fuel except for its 1.5 percent sulfur content.

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*Often used interchangeably with destructive distillation, but used here to designate the recovery of solid carbon products only, as distinguished from recovery of a variety of constituents.

[19] Wolfson, D. E., J. A. Beckman, J. G. Walters, and D. J. Bennett. "Destructive Distillation of Scrap Tires". U.S. Bureau of Mines Report of Investigations 7302. Washington, U.S. Dept. of the Interior, 1969.

Although the various gases and oils produced by destructive distillation of tires could at least be used in-plant for their fuel value, it is not yet clear that a commercially feasible separation process can be developed. The proportion of oils, gases and residues that would be produced would be determined by economic considerations. The survival or abandonment of a particular method of constituent-recovery would depend on capital and operating costs. Within the limitations of the methods which are commercially feasible, the decision to manufacture a particular product would depend on the demand for that product at the price for which it can be produced profitably. Because developmental work on these methods is still in an early stage, it is very difficult to determine accurately the probable installed costs for systems using them.

None of these methods can yet operate at a profit.[14] A carbonization process developed by Cities Service Company uses a mixture of 20 percent scrap tires and 80 percent oil to produce carbon black of good quality.[20] If all scrap tires were converted to carbon black at this rate, the output would greatly exceed the tire industry's demand for carbon black. If a mixture using 60 percent tires and 40 percent oil were used, the carbon black produced by the process would be equal to the carbon black demand of the tire industry. There is some possibility that such a mix may be technologically possible. Goodyear, which hopes ultimately to use this process to provide carbon black for the manufacture of new tires, has found the present cost of production by this method to be three to four times the cost of commercial carbon black manufactured entirely from petroleum. This cost would be likely to be considerably lower in commercial production. Firestone, which has built a pilot plant for destructive distillation, and the Hydrocarbon Research, Inc. believes 2 to 5 years of development will be required before its process can reach commercial scale, but has prepared cost projections for a 1,000 ton-per-day rubber hydrogenization plant. These projections show an annual profit of $1.8 million from such a plant, assuming waste rubber can be obtained for $5.00 a ton.[21] Firestone projects at least 5 years of development. Considerable investments in both technological research and market research will be necessary. Firestone has sought to find non-fuel uses for its carbon residual, either as carbon black for new tires or as activated charcoal, but so far has been unsuccessful. At present, the technological barriers to profitable destructive distillation appear formidable enough to have caused two major rubber producers, Goodyear and Uniroyal, to abandon the idea after having given it serious consideration in the past.[7]

The air or water borne effluents that may be expected to result from destructive distillation will depend upon the products being produced. Conventional processes for cracking petroleum into various hydrocarbon compounds are not yet emission free;[22] similar problems may be expected from the refining of the oils and gases generated by destructive distillation of tires. Hydrogenization is already known to give off hydrogen sulphide, although most of it should be convertible to recoverable sulfur.

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[20] Goodyear International Corporation. Unpublished data, Oct. 1970.

[21] Hydrocarbon Research, Inc. Unpublished data.

[22] Elkin, H.F. "Petroleum Refinery Emissions". Edited by A.C. Stern in Air Pollution, 2nd ed. vol. 3, chap. 34. New York, Academic Press, 1968. Also "Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources". Washington, U.S. Government Printing Office, March, 1970. (Nat. Air Pollution Control Admin. Pub. no. AP-68).

It is too soon to determine whether destructive distillation or hydrogenization will be a commercially profitable operation, or, if not profitable, at what cost either could be used to dispose of scrap tires. It is possible to say, however, that reserves of commercially recoverable petroleum are expected to be exhausted during the next 70 to 80 years.[23] Against this background, destructive distillation and hydrogenization provide an opportunity during the intervening years to conserve a vanishing resource and to reduce the reliance of the tire industry on a raw material that will become more expensive as the supply diminishes. In addition to the benefits from its gas and oil products, the carbon residue of destructive distillation would furnish a usable fuel, provided satisfactory sulfur dioxide controls are available, or a material (activated charcoal) increasingly required for waste treatment. As a means of disposing of scrap tires, destructive distillation and hydrogenization, once perfected, would be available indefinitely. Commercially feasible destructive distillation or hydrogenization would require large regional plants. The plants serving metropolitan areas would need to pay only the cost of local collection. Those servicing broader, less densely populated areas would have to pay both more expensive collection costs and the cost of shipping. Under these circumstances, unless regulatory authority were asserted to compel everyone to ship tires to regional treatment centers, the less densely settled portions of the country would probably continue to dispose of tires by other less expensive methods.

Destructive distillation or hydrogenization would have some effect on the existing market for the raw material from which tires are made. Because one of the most likely candidates to operate destructive distillation or hydrogenization plants would be the rubber companies that would use the end products of such plants, a possibility exists for a special economy in connection with collection and shipping of tires. The distribution system by which new tires pass from manufacturer to consumer would be the best collection system by which to return old tires to the destructive distillation or hydrogenization plants.

Finally, destructive distillation and hydrogenization would have no adverse effects on other solid waste management practices and, other than the ash from the combustion of its carbon residue, would remove all of the tires from the solid waste disposal stream.

Incineration

"Incineration", as used in this report, is distinguished from power production, destructive distillation, and carbon black recovery in one important respect; while the latter three disposal methods are important possibilities because of the benefits derived in addition to the disposal of tires, incineration is simply a means of disposal, or, more accurately, of volume reduction. In some cases, incineration may be combined with the production of steam power, but to the extent that the value of an incinerator is dependent on its capacity to produce more steam than is necessary for its own space-heating or processing, it is dealt with in this report under the use "power production".

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[23] Singer, S.F. "Human Energy Production as a Process in the Biosphere", Scientific American, vol 223, no. 3, Sept, 1970.

The possibilities for incineration are much less restricted geographically than the possibilities for power production. Rubber tires are not plentiful enough to compete with coal as a fuel for municipal scale steam generators. Theoretically, scrap tires could be absorbed in existing incinerators by normal waste-disposal methods without necessitating any significant increases in existing or projected incineration capacities.

In practice, however, the combining of tires with other wastes is hindered by several technical difficulties. In most existing incinerators, small numbers of tires can be combined with large quantities of refuse without creating any special problems. The acceptable proportion of tires is extremely limited, however, because of two factors. First, the concentration of heat generated by burning tires is much greater than that generated by most other refuse. Grates and refractories of modern incinerators subjected to the heat produced by a high proportion of tires in their loading suffer a reduction in useful life. Second, the smoke produced by burning tires requires more flue gas control than that of most other waste. Under existing modern incinerator practices, incinerators with electrostatic precipitators can consume refuse with a rubber tire content of between 1 percent and 5 percent without suffering a decline in the quality of their effluent or injury to their combustion chamber. Since scrap tires constitute only 1.7 percent of the per capita combustible waste, the use of incinerators equipped with new stack controls might provide a solution to the scrap tire problem if the slow burning rate and concentrated "hot-spot" temperatures of tire burning could be solved. Incinerators can be designed to permit the residence time (1/2 to 1 second) necessary to burn the hydrocarbons that give burning rubber its characteristic odor. The thermal concentration problem can best be avoided by limiting the concentration of tires in the charge, and mixing the tires with other waste. This can be done with whole tires, but is more easily done with tires that have been chopped.

A second alternative is to build special incinerators for rubber tires. The Continental Tire Factory in Hannover, Germany installed such an incinerator in 1964, as a means of disposing of both scrap tires and process waste.[24] Although Hannover's process waste includes paper, oil and grease in addition to scrap rubber and carbon black, its primary ingredient is tires. The principal drawback to constructing special tire incinerators is the extremely high cost.

The cost of incineration, calculated on a per-tire basis, is lower for tires mixed with other refuse than for tires burned separately. The cost of burning tires separately, however, is not necessarily out of the question. According to representatives of the company that built the Continental Tire Company incinerator, the cost of a plant designed for incinerating tires only, and having a capacity of 1 ton of scrap tires per hour, would be about $1 million. Assuming the plant operated 24 hours a day, the total cost (capital and operation) would amount to between $0.20 to $0.40 per tire. A plant of this size would service a city the size of Washington or Cleveland, and 225 such plants would service the entire United States.

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[24] Von Roll incinerator for Continental Tire Factory. The Rust Engineering Company, Division of Litton Industries. Submitted to Rubber Manufacturers Association, Environmental Meeting, Sept. 16, 1970.

Transportation costs would be lower for incineration than for some other end uses (such as reef-building) because the large number of incinerators, whether for mixed refuse or tires only, would make it possible for each plant to draw its tires from a relatively small radius. If the population and 225 plants were evenly distributed throughout the country, the greatest distance any tire would have to be transported would be about 150 miles. But with three-fourths of the population residing in urban areas, incineration plants could be located within a few miles of places where the great majority of tires are discarded. This would leave some rural areas outside the radius within which tires could be economically transported to incinerators. The problem of these rural strays, however, would be less for incineration than for end uses with fewer points of use.

The viability of any end use is heavily dependent, of course, on its capacity to reduce environmental insult. While incineration greatly reduces the total volume of unprocessed solid waste, it also produces two new categories of waste, solid residuals and airborne effluents, which present their own environmental problems. In the case of rubber tires, both of these by-products are more capable of environmental insult than the unprocessed tires from which they are extracted. The methods by which they are controlled must therefore form an important part of any strategy which uses incineration as a means of alleviating the scrap tire problem.

Even if 100 percent of the scrap tires produced in the United States were incinerated, the tire disposal problem would not be eliminated. Incineration leaves a substantial quantity of ash, which must itself be disposed of, usually as landfill. There is a possibility that the ash residual of burned tires is more active biologically than unprocessed scrap rubber.

Other than sulfur dioxide production, air pollution from the incineration of tires mixed with other municipal refuse can be controlled to meet existing standards, although the process is more difficult than with most other refuse.

Incineration of tires would be feasible over an indefinite period of time, and would have no effect upon the existing tire market. Its effects on other solid waste management practices would depend upon whether specialized tire incinerators were built. A specialized incineration program would reduce the burden of tires otherwise placed upon municipal solid waste facilities, except for tire incineration residue which would have to be disposed of. A specialized incineration program, however, would tend to divert resources from other municipal waste disposal operations if not entirely supported by special funds.

If tire incineration were to be undertaken in conjunction with the upgrading of other municipal incineration programs, any special resources allocated to tire disposal could have the collateral effect of improving facilities for incineration of municipal waste generally. The augmented air supply and additional scrubbers and precipitators necessary to ensure hydrocarbon combustion and particulate control for tire combustion would improve the quality of the total incineration effluent.

Retreading

Retreading is the most obvious and economically attractive form of tire recycling. It is, however, inherently incapable of becoming a final use for used tires, since each retreaded tire must ultimately be discarded. On the other hand, retreading can be regarded as an end use to the extent that it reduces the amount of tire waste produced in any given period. In this sense retreading is already a significant end use, since without retreading there would be some 22 percent more passenger tires discarded per year. The present production of waste could be further reduced by: (1) increasing the life of each retread; (2) increasing the percentage of tires which are retreaded rather than replaced; (3) increasing the number of times a carcass can be retreaded. To some extent, of course, these approaches are interdependent. Sales of retreaded tires are to some degree affected by the reputation of retreading, which is, in turn, dependent on retread performance. It is significant, however, that the percent of all replacement passenger tires that are retreaded (about 22 percent) is not far below the percent of used tires that are in good enough condition to retread (about 35 percent). At least in some areas, the demand for retreads exceeds the present supply of retreadable casings. Although the demand for retreaded tires could certainly be increased by an improvement in the quality, an increase in the use of retreads in not necessarily dependent on such improvement. There are a number of obstacles to completely satisfactory retreading, but they can all be overcome given sufficient control over the tire cycle. Most of the obstacles are the result of variations of one form or another. Different tire manufacturers use slightly different compounds of elastomers and fillers to make their rubber. The adhesive used to attach new tread (called "camelback" in the industry) to a used carcass is "compound-specific" (i.e., an adhesive mixture that works well with one compound may work less well on another).

A tire to be retreaded is placed in a circular mold and subjected to heat and pressure in order to vulcanize the bond between carcass and camelback and to extrude the camelback into the engraved tread pattern on the outside mold. Different tire manufacturers allow different degrees of minor variation in size for each standard tire size. These variations will affect both the amount of smooth rubber left on the carcass by the buffing process that precedes the molding, and the effectiveness of the molding process itself. Finally, there are variations in the interface between fabric and original tread in new tires, some of which cause the thin layer of original rubber left on the fabric after buffing to separate from the carcass during retread use.

There is persuasive evidence that retreaded tires can perform as satisfactorily as new tires in nonpassenger tire use. Retreads make up 22 percent of the replacements sales in the passenger car market but comprise 37.5 percent of the tire sales in the truck and bus market. The average tire for a truck or bus is retreaded 1.8 times, and many are retreaded four to five times. Large bus lines typically do not buy tires but rent them from tire manufacturers who, through their own employees, maintain tire pressures and make all decisions when to change and retread tires. Aircraft tires on commercial jet aircraft are commonly retreaded four to five times notwithstanding the high performance and safety demands placed on them; propeller aircraft tires are sometimes retreaded as many as 15 times.

At present, passenger car tire design is carried out without any attention to tire characteristics that would improve retreading.

There are at least two areas in which significant increases in retread use could be implemented without further improvements in retread bonding technology. First, the percentage of tires which are discarded in retreadable condition could be increased. Many tires are rendered unretreadable when the beads are damaged during removal from the rim. Protection of the beads during tire removal would not require changes in technology; it would only require changes in the attitudes (or incentives) of the retailers who remove the majority of tires from their rims.

The percentage of these tires that are discarded in retreadable condition could also be increased if consumers would not allow their tires to become completely worn. Because bald tires are unretreadable, they must be discarded by retreaders who are hard pressed to meet the existing demand for retreads because they cannot obtain enough tires in good condition. Again, the reduction of excessive wear is not a matter of technology, but of attitudes.

If consumers had incentives to trade in their tires when 1/16 inch tread remained, it has been estimated that the percentage of tires that would be discarded in retreadable condition would rise by more than 35 percent.[7] Motor vehicle safety standard number 109 issued by the National Highway Safety Bureau, Department of Transportation, requires all passenger car tires manufactured after August 1968 to incorporate a tread wear indicator that will become visible when the tire has worn to a tread depth of 1/16 inch. Nineteen states now require more than 1/16 inch of tire tread as part of their periodic automobile safety examination.

For the retreader, the problem is not simply that the number of retreadable tires is not great enough to meet the demand, but one of economics. The higher the percentage of discarded tires that have bead damage or excessive wear, the higher become the costs of the sorting and culling required to obtain the required number of reusable carcasses. The fact that the overall number of retreadable tires discarded is great enough to meet the demand for retreads at prevailing prices does not necessarily mean that those tires can be profitably collected and sold at those prices. Many tires that *could* be retreaded to meet existing demands must be passed over by the retreader because they are not sufficiently aggregated for profitable collection or because they are too far away.

This is most frequently the case with tires discarded at filling stations where the number of tires left is too small to warrant frequent visits, and where the amount of available storage space is too small to permit accumulation of tires over a long period.

The second area in which significant increases in retread use could be implemented without further improvements in bonding technology is that of tire maintenance.

Underinflation produces an excessive degree of flexing in the tire carcass when the car is in motion, and this flexing in turn builds up an excessive amount of heat. In both new tires and retreads, excessive heat is a principal determinant of tread wear. In retreads, this problem is especially crucial since it is the buildup of heat at high speeds which causes treads to become free of their bondings and fly off carcasses. More widespread compliance with tire manufacturers' tire pressure recommendations would reduce the heat buildup and thereby effect significant improvements in new tire durability, in the proportion of used tires that could be retreaded, and in retread life, all of which would lessen the tire waste disposal problem.

Beyond a certain point, of course, the amount and quality of retreading cannot be increased without further advances in technology. The widespread use of retreads on aircraft wheels underscores the possibility of building passenger car retreads which are durable and safe for high-speed driving.

Alternative approaches to the solution of this problem would be (1) to accelerate research and development until a bond is found which can make retreading competitive with new tires even when used for the combining of a wide variety of synthetic rubber compounds; (2) to standardize the manufacture of passenger car tires to the extent that all new tires are sufficiently similar in composition to permit significant improvements in retreading results without further improvements in retreading technology.

Neither of these approaches appears feasible in the immediate future. The first approach would require a considerable allowance of both money and time, and even with these resources rubber chemists are not certain that the objective can be achieved. The second approach would give retreading an influence on new tire design that its waste reduction function would not warrant. Barring the use of an almost indestructivle carcass (one which can be retreaded three or four times), retreading would not eliminate the bulk of the scrap tire problem. Representatives of one major tire company were of the opinion that a 100,000 mile carcass is within the present state-of-the-art and such mileage could possibly be achieved with existing steel radial carcasses.[7] Conversion of the tire industry to the manufacture of a carcass intended for retreading up to 100,000 miles (or the full life of a car) would reduce tire waste by as much as 80 percent, but would necessitate major changes in the tire industry.

The future of retreading is threatened, however, by the fact that technological advances in new tire design are guided by a variety of considerations not conducive to improvements in the amount or quality of retreading. The advent of glass belted tires, for example, has caused some unforeseen complications for retreaders. The first generation of these tires proved difficult to retread in some cases, due to inconsistencies of shape combined with the greater rigidity of glass belted carcasses. The consistency of these tires is improving, however, and if sizes and shapes can be controlled more carefully, carcass rigidity appears likely to change from a liability (from the point of view of retreading) into an asset.

A major deterrent to greater consumer acceptance of retreading is the availability of inexpensive new tires at competitive prices. These tires normally do not have the structural strength necessary for subsequent retreading, and increase the retreading costs in collecting and sorting. They have a competitive market advantage arising out of the inherent psychological benefit of being new even though in performance they may be less satisfactory than a properly retreaded used tire.

Roadbuilding

There is considerable precedent for using scrap tires in roadbuilding, either in the roadbed as an aggregate or in the surface itself as an asphalt additive. There is some evidence that rubber improves road surfaces in terms of both skid resistance and wear and makes a superior road patching compound.

It is estimated that the addition of 5 percent rubber to all new asphalt used in roadbuilding or road repair in the United States would absorb the current annual output of scrap tires.[25]

In general, the effectiveness of rubber as a road additive is somewhat doubtful. Goodyear markets a synthetic rubber asphalt additive made of new rubber which is reported to increase road life somewhat, but which also raises the cost of road construction substantially.[4] Reports on the effectiveness of reclaimed rubber additives are mixed, and asphalt samples containing 10 percent reclaimed rubber are visibly too soft for highway use.[7] Chopped rubber used as a roadbed aggregate was reported to be equal but not superior to crushed rock.[7] A chopped rubber layer at the interface between road surface and roadbed has been reported to improve road quality.

Although all the end uses under consideration here provide means of substantially reducing the total solid waste management task, some leave a major portion of this task in the form of either a deferred tire disposal problem (as with retreading) or a different kind of solid waste problem (as with incineration). The roadbuilding solution is more nearly complete because it leaves virtually no solid waste either in original form or in residual form.

The possibility of incorporating rubber into roads has been given at least sporadic consideration for the past 45 years. More experimenting with rubberized roads has been done in Europe than in the United States, but even in this country some 10,000 miles of rubberized roads have been laid.[26] In the construction of such specialized surfaces as bridge pavements, tennis courts, playgrounds, and running tracks, rubber compounds have achieved considerable popularity. It should be emphasized, however, that most of these surfaces are made of new, specially manufactured synthetic rubber compounds rather than of "old" rubber from discarded tires. As a roadbuilding material, reclaimed rubber cannot be assumed to be the physical or economic equivalent of new rubber; yet very little is known about the actual costs and benefits of reclaimed rubber in highway construction.

Compounds made largely of reclaimed rubber (such as U.S. Rubber Reclaiming Company's Ramflex) have been used in road surfacing projects in at least 52 projects in nine states.[27] Most of the projects in which proper controls have been maintained were begun in the early or mid 1960's, and most of these have not yet shown any clear superiority for rubberized asphalt.

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[25] Snyder, J.D., and R.F.Hickox "Downwind: Akron Stinks", Rubber World, vol. 161, no. 3, Dec. 1969.

[26] Anderson, E.V. "Rubber: A $16 Billion Industry Turns on Tires", Chemical & Engineering News. vol. 76, no. 15, July 14 1969.

[27] Midwest Rubber Reclaiming Company. Unpublished data, 1969.

For example, the State of New York has been checking one experimental section since it was installed (along with a nonrubberized control section) in Utica, New York, in June 1965, and has observed no difference between the two sections. Other rubberized sections which are indistinguishable from their nonrubberized counterparts are located in highways in Buffalo, Syracuse, Rochester, Detroit, and Oklahoma, and on several parts of the New York Thruway. In Etobicoke, Ontario, a section of Ramflex was found to be indistinguishable from its control section after seven years. On the other hand, a number of other projects have shown minor but consistent differences between rubberized and nonrubberized pavements. In these projects, the rubberized sections have shown less of a tendency to shove, crack, and ravel than the controls. Such results have been found in Elmira, New York; Niagara Falls, New York; Hook Mountain Road, New Jersey (near Pine Brook); Phoenix, Arizona; San Diego and Los Angeles County, California. In Hartford, Connecticut, a control section was found to have two and a half times as many cracks as the experimental rubberized section 17 months after installation, but 2 years later the experimental and control sections were equally bad. There is no report of rubber having a *negative* effect on a road, although there are many cases in which no positive effect has been observed.

The present cost of adding rubber to asphalt (usually in concentrations of 3 to 8 percent) ranges from $1.50 to $2.50 per ton of mix.[26] This cost would have to be regarded as essentially unrecoverable, even though the potential durability of rubberized roads leaves open the possibility of long term savings in maintenance.

One recent research and development effort, however, has reported very substantial improvement in durability of road repairs, and potentially in new road construction, using rubber and asphalt mix as a film between the old road surface being repaired and the surfacing material. The process uses a mixture of one-third ground scrap tires (1/8 inch fragments), one-third sand, and one-third asphalt and water emulsion. Tests indicate that 1/4-inch film of mixture should increase the surface ability of a road to withstand expansion and contraction without cracking by 440 percent over road repairs done without the rubber film interface. [28, 29, 30] Field testing of this Stress Relieving Interface began in August and September 1970, and results will not be available for some time. A preliminary estimate is that the annual output of scrap tires would furnish enough ground rubber to apply this prodess to approximately 30,000 of the 200,000 miles of resurfacing performed annually in the United States.[30]

Artificial Reefs

One possible end use for scrap rubber tires is the construction of artificial reefs in ocean waters. The idea is not new; the Bureau of Sport Fisheries and Wildlife (BSFW) has been experimenting with such reefs

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[28] Bynum, D. Jr., J.F. Evertson, H.O. Fleisher, and D.R. Ray. Materials Characterization for a Pavement Stress Relieving Interface. Unpublished data. College Station, Texas A&M University, 1970.

[29] Bynum, D., B.M. Gallaway, and B.D. LaGrone. Analog Tests of Pavement Stress Relieving Interface. Unpublished data, Nov. 25, 1970.

[30] James, L.L. "Ground Tires Reduce Pavement Cracking", The American City, vol. 86, no. 2, Feb., 1971.

since 1965, and has collected a quantity of data relating to their value as a means of solid waste disposal.[31]

From the point of view of the BSFW, the primary purpose of artificial reefs is to provide a habitat for fish in certain coastal waters where fish nutrients are plentiful but protective structures on the ocean bed are scarce.

Reef construction must be conceived and implemented only as a means to enhance the marine environment. The Council on Environmental Quality reported in October of 1970:

> Use of waste materials to rehabilitate or enhance the marine environment, as opposed to activities primarily aimed at waste disposal, should be conducted under controlled conditions. Such operations should be regulated, requiring proof by the applicant of no adverse effects on the marine environment, human health, safety, welfare, and amenities.[32]

In the construction of prototypes, the BSFW has relied on scrap materials because of their low cost. Three types of reefs have been built--from scrap automobile bodies, from ship hulks, and from rubber tires. Each type has been evaluated on terms of several criteria. These include: (1) life expectancy of the material; (2) surface area; (3) encrustation characteristics; (4) variability of reef design. Rubber tires have been given the highest rating of the three materials. Whereas steel automobile bodies disintegrate rapidly in salt water (frames last a number of years but sheet metal disappears rapidly), rubber tires show no measurable deterioration in 10 years of submersion. The surface area of a tire is relatively high, and each tire provides protective spaces for small fish. At New Jersey latitudes encrustation begins within 2 weeks and is completed in less than 2 years. Designs of reefs constructed of tires are infinitely variable, since individual tires can be combined in units of any number and in a variety of configurations. The BSFW has concluded that synthetic reefs are a desirable enhancement of the marine environment, and that the best known material for such reefs is scrap rubber tires.

As an end use, such reefs could accommodate 100 percent of the present volume of scrap rubber tires for several decades. The BSFW estimates that 1.6 billion tires would be required to build reefs on sites warranted by present recreational fishing pressure on the Atlantic Coast. This estimate is based on the assumption that each reef would be 2 feet high. Since approximately 180 million tires are scrapped each year, the immediate capacity of the Atlantic Coast sites would be enough for 8 years. This capacity is based only on current recreational fishing demands. Although the BSFW is concerned primarily with recreational fishing, the potential pressure of commercial fishing is far greater. If justified by larger fishing demand, the height of each reef could be made many times greater than 2 feet. The use of artificial reefs could also be extended to the Gulf Coast and the Pacific Coast, and possibly to other waters as well.

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[31] Stone, R.B., C.C. Buchanan, and F.W. Steimle, Jr. "An Investigation of the Use of Scrap Tires As Artificial Reefs". Unpublished report, Bureau of Solid Waste Management, 1970.

[32] "Ocean Dumping; a National Policy", A report to the President prepared by the Council on Environmental Quality. Washington, U.S. Government Printing Office, Oct., 1970.

The potential capacity of such reefs, therefore, is sufficiently great to satisfy the tire disposal needs of the United States for many decades--probably longer than the problem itself will continue to exist in its present form.

While artificial reefs would be a long-term solution, they would also be a limited one. No lead time would be required for implementation; only the collection procedures and administrative structure required for a large-scale, reef-building operation would have to be worked out in advance. No delays would be necessary for research and development (except perhaps in the area of environmental effects), since such an effort by the BSFW has already reached the point at which nonexperimental implementation could begin. This would not preclude the continuation of additional research.

At the present time, there are 28 small tire reefs in place on the East Coast. Cost figures compiled in connection with these reefs assumed that tires were delivered free to a dockside staging site. In order to be effective, the tires have to be ballasted and, if possible, connected together to obtain a high profile above the bottom and to prevent them from scattering. The average major costs per tire were: ballasting and connecting material, \$0.22; labor, \$0.57; and transportation to reef site, \$0.66; or an average total cost of \$1.45 per tire. A study is now underway to develop a mass production method that would reduce labor and material costs. If reefs were used as a principal means of disposal, transportation costs from noncoastal states would be a major additional factor.

The environmental pollution effects of artificial reefs are not entirely known. Observations made by the BSFW suggest, however, that there may be no measurable adverse effects at all. In at least one case it was noted that tires submerged in ocean water for 10 years showed no signs of deterioration.[31] The BSFW's 5-year-old tire reefs, which are composed of several thousand tires, also show no sign of deterioration. BSFW has conducted chemical analysis of sea water for evidence of contamination from prolonged exposure to tires; no such contamination has been detected. In another experiment, tropical fish exposed to 2 pounds of ground rubber in a 10-gallon fish tank displayed no evidence of injury during a 2-year experiment. It is not known, however, what happens to tires left in the ocean longer than 10 years; or that real ocean conditions (currents, contact with abrasive materials, exposure to corrosive chemicals, changes in temperature, etc.) may not produce changes heretofore unanticipated in laboratory investigations.

The difficulty of measuring the effects of tires on the ocean environment is compounded by the difficulty of forecasting what demands will be made on that environment in the future. It is almost certain that the ocean floor, particularly those parts of the ocean floor which are most hospitable to marine life, will be required to serve functions other than that of providing habitation for fish. Potential conflict between those functions (whether they be scientific, aqua-cultural, recreational, commercial or otherwise) and the presence of large masses of synthetic rubber, may be an important consideration in evaluating artificial reefs as an end use for rubber tires.

Reuse Intact

The oldest and simplest method of disposing of used tires--other than simply throwing them away--is to use them intact for nontransportational purposes. Traditional nontransportational uses absorb only a very small fraction of the total number of scrap tires generated. There are other uses, however, that would be capable of absorbing significant quantities of whole scrap tires.

The principle projected uses relate to impact (energy) absorption and erosion control. In impact absorption uses, tires are stacked in various configurations, linked together with flexible connectors, which are attached to docking facilities or emplaced as barriers around obstructions near, or between adjacent lanes of highways. An estimate has been made that in a dock application 50,000 scrap tires per mile would be utilized, at approximately 1 ton of scrap tires for every 10 feet of dock. In the highway safety application, the number of tires that could be employed would be limited only by the space available for barrier construction.

For use in erosion control, tires are laced together tread to tread, into mats, that are then emplaced along river banks, or across sand dunes. Calculations have been furnished by Goodyear, to the effect that a typical continuous mat, 25 feet wide, would require 87,000 tires per mile of shoreline.[33]

Tires can be used for retaining walls and as ground cover for soil erosion control. Retaining walls consisting of stacked tires have several advantages over conventional materials. They are much easier to handle than stone (a properly reinforced wall of tires can be built many times more rapidly than an equivalent wall of stone), and they deteriorate less rapidly than wood. Structurally, a wall of tires can be made exceptionally stable when strung on vertical piles driven into the ground, and filled with concrete or dirt.

Such end uses could absorb large quantities of tires for a limited time. These share one drawback. One of a scrap tire's detriments is its characteristic appearance. Worn tires deposited as litter on the landscape are unsightly. A widespread use of scrap tires that emplaces them in large numbers along roadway or shorelines, in installations that are permanent and prominent, will have, at least to some viewers, aesthetic drawbacks.

Protein Manufacture

The synthetic rubber that is used to manufacture tires consists of hydrocarbon polymers. The chemists who construct compounds of synthetic rubber are, in effect, arranging and rearranging molecules consisting of hydrogen and carbon. This has led to a preliminary investigation into the ultimate possibility of converting the constituents of rubber into an edible protein. In the words of a Goodyear chemist: "Our basic thoughts here are to take advantage of the fact that rubber is a polymer that can be converted to another useful polymer."

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[33] Goodyear Tire and Rubber Co. Unpublished data, Sept. 17, 1970.

At the present time, the investigation into this end use is too preliminary to permit any estimate of its feasibility, costs, or of the amount of time that successful development might take.

CHAPTER 4

STRATEGIES

General

The discussion of strategies that follows assumes that, except where expressly modified, existing recycling and reuse of tires through reclaiming and retreading continues.

Tire Collection

In the present tire market, consumers, even in rural areas, tend to buy their replacement tires from tire retailers who will change tires for them. If the retailer does a large volume of business or has a large storage area, transportation of his accumulation of used tires to a retreading plant is economical. If he does not, he must discard these and usually does so by unauthorized disposal. Several strategies seek to furnish incentives through which the collection process could be made all-inclusive. In some, the retreader is paid to collect tires from small retailers. In others, a person or organization (usually a municipal government) is paid a bounty for disposing of a scrap tire through an approved reuse or recycling method. These incentives will not only affect tires in the hands of retailers and retreaders but should also reach tires that have already been abandoned, or used tires in the possession of owners who, for one reason or another, have not surrendered them to retailers when buying replacements. The proposed payments must be large enough to make it possible for the recipients (municipalities or retailers) to pass portions of the payments on to any persons furnishing them with tires. Once the retreader or approved disposer is able to offer payment for tires, tire scavenging becomes commercially attractive to the extent that the available bounty payments exceed the costs of scavenging. In some cases, the municipality or retreader may enter directly into the scavenging business. This would be expecially likely near sites where large concentrations of scrap tires have accumulated. In most cases, however, the municipality or retreader would serve as a market for tires collected by such low overhead scavenging enterprises as volunteer groups and junk dealers, and for individual consumers willing to make a modest effort to obtain some cash benefit in exchange for used tires.

Point at which tax is applied. Although there are a number of different points in the flow of tires from manufacturer to consumer at which a tax could be imposed, we have used the same point of taxation in nearly every strategy; a tire disposal tax, imposed at the time of sale upon the consumer. We have chosen to do so because imposition of a tax at any other point in the chain would ultimately be passed on to the consumer in the form of higher prices. To raise the price at an earlier point in the flow would have the effect of raising the cost per tire from that point on so that the costs of the inventories of each possessor would be higher than they would be otherwise. The result would be a requirement for more operating capital at each point in the flow without any other alteration of it. The price rise passed along in this manner would be augmented by an artificially increased overhead charge.

Form of subsidy. There are a number of forms in which a subsidy can be paid. Many of them are easily recognizable as subsidies; some are not. Federal subsidies at the present time range from outright payments (Aid to Dependent Children, G.I. Bill benefits) through conditional support subsidies (loan guarantees to overseas investors) to indirect subsidies such as tax exemptions and deductions. The shortcomings of indirect subsidy through tax examption have been criticized on the grounds that, once granted, the amounts of such subsidies are unknown and cannot be controlled, and that they conceal certain types of Federal support from the public while other forms of support receive disproportionate publicity.

For these reasons, and because pollution abatement is currently politically popular, we have chosen to express the financial support described in each strategy in terms of direct subsidy. Political or economic circumstances independent of solid waste management considerations may make some degree of indirection more appropriate at some other time. The subsidy values we express could be translated into less direct terms if it would serve the public interest.

Trust Fund

For many of the following strategies, we have suggested the imposition of a tax to cover the costs of tire disposal at the time of sale and the proceeds be paid into a Federal tire disposal trust fund. We have used the trust fund device in order to isolate the costs and revenues associated with scrap tire disposal or reuse for study. The trust fund procedure is also intended to suggest that the tax revenues required for each tire disposal strategy should be fixed at a high enough rate to cover the costs associated with that strategy. There are valid arguments against the creation of special trust funds: their tendency to be self-perpetuating, to generate make-work when their revenues exceed needed expenditures, and their invulnerability to changes in national priorities. It is outside the scope of this study to deal with these generalized shortcomings of trust funds. We use the trust fund concept for descriptive purposes to emphasize the self-supporting character of the strategies we suggest. If these concepts are valid, funds collected at the time of tire sales could just as easily be included in, and paid from, the general revenues.

Criteria

Although this report will not attempt to present a definitive rank ordering of strategies, we discuss the strategies we have considered in terms of eight criteria. We have used these criteria, after assigning weighted values to them, to select a preferred strategy from among those under consideration. Several alternative formulations of criteria were also considered, some more detailed than others. The criteria used here were preferred because they appeared to permit application to more alternatives without modification than alternative formulations.

Although the criteria appear to be self-explanatory, individuals often interpreted them differently in practice. The following amplification may help to explain the indended meanings.

1. How soon will the strategy be technically feasible? We contrasted strategies that would be implemented immediately with those that were based on technologies that had not been developed. The criterion was concerned with availability of technology, however, and not with time lapse that implementation would require, e.g., for passage of legislation, or construction of plants or equipment. The time alternatives considered were: the present, within 5 years, 5 to 10 years, and more than 10 years.

2. How much land/air/water residual does the specific use leave? This criterion deals with pollutants resulting from the end uses relied upon in a strategy. It is important to bear in mind that it does not purport to describe the number of tires not recycled or otherwise acceptably used. That factor is dealt with under criterion 6 below.

3. How great a cash cost or benefit will result? This criterion aggregated costs to all sectors of society: consumer, industry, disposal agency and government. Cost figures for many strategies involve a sufficient degree of undertainty to make dollar approximations misleading. We described the increments as: substantial economic net benefit, small economic net benefit, small net cost and substantial net cost. Reference to the cost figures appearing at the close of Chapter 3 will permit rough approximation of the costs of most of the strategies presented here and of others not identified here.

4. How much nonmonetary benefit will be recovered? Nonmonetary benefits to different sectors were aggregated, and considered in terms of benefits to the whole society. Nonmonetary recreational benefits to sportsmen enjoying improved fishing over tire reefs, for example, were considered as nonmonetary benefits. Commerical fishing benefits would be evaluated under criterion 3. The aesthetic benefit resulting directly from disposal of tires was not dealt with under criterion 4 except where a strategy would encourage the reuse of tires heretofore discarded.

5. How long will this strategy be possible? Some strategies rely upon end uses that will only be possible for a limited amount of time. We evaluated strategies according to whether they could continue for up to 10

years, from 10 to 15 years, from 15 to 20 years, or more than 20 years.

6. How much of the yearly output of scrap tires could the strategy absorb? Although some strategies purport to deal with tire recycling and reuse as a whole, they nevertheless must be evaluated with the knowledge that their implementation will not result in the recycling or reuse of all tires. The reclamation of tires being discarded in lightly settled rural areas, for example, may not be possible within the economic limits of a strategy that appropriately deals with a very large proportion of the total of scrap tires. Other strategy alternatives may reach all tires, and reduce the number of scrap tires by 5 percent to 15 percent at very slight cost. This criterion was to distinguish among strategies along this dimension.

7. How much will the strategy change the existing tire market? There is at least a strong likelihood that disruption of an existing market will lead, for a time at least, to a reduction in its efficiency. For the tire market this would mean interruption in the supply of tires to points at which they are needed with resulting artificial increases in costs and prices. Strategies that would cause market disruption ranging from governmental specification of rubber compounds to incentive programs that would reverse the market shares of new and retread tires have been treated, as a class, as undesirable.

This criterion only indirectly dealt with the question of degree of Federal involvement. To decide whether a given strategy involved slight or serious governmental involvement was a task that resulted in greater subjective differences among persons taking part in evaluation than arose elsewhere during the development of criteria. For this reason, the decision whether a given strategy was a high or low profile Federal involvement was left to be stated qualitatively as part of the narrative description of preferred strategies.

8. How compatible is the strategy with other solid waste management practices? Some strategies remove tires completely from the responsibility of solid waste management, and still others increase somewhat the burden on advanced solid waste management facilities, others make available resources to provide and improve these facilities. We evaluated strategies, in part, by the extent to which they assisted in, or interfered with, disposal of all waste.

Strategy A

End Use:	Retreading and increased use of original tires.
Explanation:	Estimates suggest that new tire mileage can be adversely affected by improper tire pressure, thereby reducing tire life by up to 55 percent. Research by the Bureau of Standards indicates that pocket tire gauges and filling station pressure gauges are typically inaccurate enough to do more harm than good. Retreaders must discard from 50 percent to 75 percent of the used tires they examine because they are unfit to retread. Tires with too little rubber left on them are unretreadable. Damage to tire bead

during dismounting also makes some tires unretreadable. This strategy seeks to incrase new and retread tire life and leave as many tires as possible in retreadable condition.

1. Charge: None

2. Payment: None

3. Regulation: Require that proper tire-pressure recommendations and tread-depth indicator regulations be posted in all automobile and tire retail outlets and appear on labels affixed to all new and retreaded tires.

4. Education: (a) Conduct a continuing public education program, primarily through public service announcements, by the National Highway Safety Bureau on the safety implications of 1/16 inch tread depth and on the existance and function of tread depth indicators, coupled with a program to encourage all states to adopt 1/16 inch tread depth as an auto safety inspection requirement.

   (b) Conduct a continuing public education program through public service announcements and other media, by the National Highway Safety Bureau on proper tire inflation and its effects on both safety and wear. Emphasize the importance of owning a tire pressure gauge.

   (c) Compile data on relationship between bead damage and cost of disposal. Provide this data to all tire retailers.

5. Research and Development: A brief research and development program should be carried out to develop better pressure gauges for consumers and filling stations.

Evaluation

Strategy A has the advantages that it could be put into effect immediately, in large part without the need for legislation. It involves the Federal government only to a very slight degree in the operation of the tire market and in municipal solid waste management. It also has the effect of reinforcing the highway safety programs of the National Highway Safety Bureau.

1. How soon will the strategy be technically feasible? Immediately.

2. How much land/air/water residual does the specific use leave? No active pollutants are generated by the retreading industry. Buffings, the powdered rubber that is ground off the face of used tires before retreading, are produced in the amount of 94.7 million pounds a year, 1 million of which is used by the reclaiming industry and the remainder dumped.

3. How much cash cost per unit will be unrecovered? The cost of the strategy is very low. It consists of preparing publicity material for distribution through public service channels and of paying for a very small research and development program.

To the consumer, the strategy means only the price of an air pressure gauge, and foregoing the use of his tires when they have less than 1/16 inch of tread remaining. Beyond this, the increased tire care program does not impose costs. It lowers the retreader's cost of inspection and increases his profits since a higher percentage of retreadable carcasses means fewer tire inspections to satisfy his needs. This should permit a reduction in the price of retreads and increase their sales.

4. How much nonmonetary benefit will be recovered? The principal nonmonetary benefit of the strategy is increased highway safety. Tires with 1/16 inch tread or less remaining have a risk of disablement that is 10 times the risk of disablement in new tires; tire pressure has a very strong effect on automobile handling characteristics.

5. How long will this strategy be possible? Retreading theoretically will be possible as long as pneumatic tires similar in construction to today's tires are produced. Tire engineers are divided on the retreading problems that are associated with bias-belted tires, as a result of experience during the first year of large-scale, bias-belted production. Bonding difficulties were attributed variously to irregular carcass shape and to the need for different molding equipment to accommodate the more rigid carcasses. The consensus of the tire engineers we contacted was that the bias-belted retreading problems were temporary and would diminish as experience with both fabrication and retreading of bias-belted tires increased.

6. How much of the yearly output of scrap tires could the use absorb? The principal drawback of an increased tire life and retreading strategy is that it does not provide an end use for tires but only prolongs use and reduces the rate at which scrap tires are generated.

Twenty-seven percent of all tires in use are underinflated by 4 psi or more. Reducing tire pressure 4 pounds below automobile manufacturers recommended pressures reduces tire life 10 percent. Nonetheless, combining the available data on the percent of tires maintained at given pressures with the effects of these pressures on tire mileage indicates that a total annual saving of 5.1 percent of passenger car tire wear would result from an effective tire inflation maintenance program The effects on the retreading industry of a program that resulted in discarding of tires when they reached 1/16 inch tread depth and of a program to reduce bead damage are harder to estimate; the combined effects on tire discard are not likely to exceed 10 percent.

7. How much will the strategy change the existing tire market? The effects of the strategy will be slight except to the degree that decline in retreading costs permit retreaders to claim a larger part of the low-cost new tire market.

8. How compatible is the strategy with other solid waste management practices? The only effects the strategy would have would be to increase

the quantity of buffings and decrease the quantity of scrap tires entering the waste stream.

Strategy B

End Uses:	Roadbuilding, incineration, or landfill.
Explanation:	Although experiments to date to incorporate ground scrap tires directly into asphalt have had only marginal mixed success, chopped tire fragments used as one of the layers of base for an asphalt road have improved road durability. Whole tires burned in the augmented air supply environment in modern incinerators are troublesome, not primarily because of their combustion by-products but because their concentrated high thermal content damages the grates and refractories of the incinerators. This concentration of heat can be overcome by chopping the tire and distributing it over other municipal solid waste. Whole tires that are incorporated into typical sanitary landfill in truckload concentrations compress and expand during compaction and work their way to the surface during settling; fragments of tires do not display this characteristic. Although whole tires can be distributed with some effort, during either incineration or landfill, chopping reduces the defficulty. All of these circumstances indicate that tire bead removal and shredding or chopping equipment available at the municipal level would permit flexibility in selecting one of these reuse or disposal methods. Existing tire chopping equipment is not entirely satisfactory although it is used by the reclaiming industry and in connection with some incinerators.
1. Charge:	Add a disposal fee tax to the cost of each new tire to be paid into a Federal trust fund.
2. Payment:	(a) Pay from the trust fund to the retreader, retailer or consumer, the cost of delivery to the appropriate municipal authority that operates an acceptable solid waste disposal facility or is responsible for road construction and maintenance. (b) Pay from the trust fund to the municipal authority the capital cost of tire bead removal equipment and tire shredding or chopping equipment.
3. Regulation:	None.
4. Education:	(a) Inform municipal officials of the availability of Federal funds to pay capital costs of bead removal and shredding or chopping equipment. (b) Inform tire retreaders, etc., of availability of tire transportation funds.

(c) Inform municipal officials of suitability of chopped tire for road subsurface, incineration and sanitary landfill.

5. Research and Development: A short-range development program should be undertaken to improve the performance and lower the cost of tire-shredding equipment.

Evaluation

A principal advantage of this strategy is that it can easily be adapted either to variations in local conditions (such as seasonal deterioration of local roads), or to changes in technology (such as the development of more heat-resistant incinerators), or to differences in existing municipal waste disposal practices and facilities. No sophisticated equipment is required, and no long-distance transportation of tires is called for; scrap tires are ground up and disposed of through whichever of several available channels seems most appropriate at a given time.

1. How soon will the strategy be technically feasible? The strategy could be implemented immediately.

2. How much land/air/water residual does the specific use leave? This would vary according to the proportions of tires channeled to the various end uses. The greater the percentage of tires used in roadbuilding or landfill rather than incinerated, the less emissions would be created by the strategy.

3. How much cash cost per unit will be unrecovered? None of the three end uses involved in this strategy is likely to be profitable. The cost of the strategy regardless of the mix of end uses would be minimized by the coordination of tire disposal with other activities already conducted by municipal agencies.

4. How much nonmonetary benefit will be recovered? The strategy would enhance the operations of municipal governments.

5. How long will this strategy be possible? As long as any of the three specified (or future unspecified) end uses for chopped tires remain viable, this strategy can continue. At least one, incineration, is likely to become more rather than less viable as fire-wall tolerances and pollution controls are improved. Only landfill is likely to become less available in the near future.

6. How much of the yearly output of scrap tires could the use absorb? The strategy would absorb a very large percentage of the United States output of scrap tires since it would be applicable in virtually every American community. There would undoubtedly be a larger discrepancy between theory and practice for this strategy than for some other, since implementation would depend on the responsiveness to Federal incentives of thousands of community leaders rather than of a few corporate executives or Federal officials.

7. How much will the strategy change the existing tire market? The retreader, by having one of his significant costs reduced, would be able to examine more tires for the same cost, or examine the same number of tires at lower cost. In either case, retreading would obtain a competitive advantage over low-cost, low-performance, new tires.

8. How compatible is the strategy with other solid waste management practices? The equipment necessary to chop tires is essentially similar to equipment used to shred material for composting and to prepare other organic material for easier handling. Tire-shredding equipment made available under this strategy would assist other municipal waste management.

Strategy C

End Uses:	Power production
Explanation:	Power production is an end use that could produce an economic benefit. The capital and operating costs of a tire-burning power plant would be higher than those of a coal-burning plant. A subsidy would be necessary to bring about tire-fueled power production. Plants large enough to operate economically, even as peak load supplemental power facilities, would require the scrap tire output of a large metropolitan area or comparable region.
1. Charge:	Add a disposal fee tax to the cost of each new tire to be paid into a Federal trust fund.
2. Payment:	(a) Pay to the retreader part of the cost of delivery to the regional authority that will operate a tire-burning power plant. (b) Pay those portions of the operating and capital costs of regional, tire-burning power plants that would exceed costs of conventional fossil fuel plants. (c) Pay capital costs of any tire-bead removal and shredding equipment needed to prepare tires for power production.
3. Regulation:	None.
4. Education:	None.
5. Research and Development:	Federally-supported research and development of improved tire-burning power plant design.

Evaluation

Synthetic rubber is made from petroleum products. Formed into tires, it is distributed approximately according to population density. In effect the tire life cycle pays the cost of transportation of the rubber and its fiber content, from the point at which it is mined to the point at which it is discarded. The tire cycle also generates sufficient funds to pay the cost of delivery of scrap tires to a single collection point for each metropolitan area, since retreaders typically pay equivalent costs to dispose of their unretreadable tires.

Since tires represent a high heat-content hydrocarbon fuel delivered free to large metropolitan areas, it seems desirable to use them in place of other hydrocarbon fuel for which the cost of transportation must be borne by its fuel use alone.

1. How soon will the strategy be technically feasible? Small power plants have been built in England and operate economically to produce limited amounts of electricity. Nevertheless, pilot plant construction and some further development would probably be desirable before building commercial-size plants. Full-size plant construction could be carried out within 5 years.

2. How much land/air/water residual does the specific use leave? The existing data on emissions from rubber-fueled power plants is sparse. Experience with rubber-burning incinerators indicates that the residence time necessary to complete combustion of rubber hydrocarbons can be provided in a properly designed combustion chamber. The particulate emission should be no greater than coal; the sulfur emission comparable to that of relatively low-sulfur coal or oil.

3. How much cash cost per unit will be unrecovered? The cost figures for power production make tire-burning power a promising low-cost means of disposal of tires but not a profitable way of generating power. The problem is that there are so few tires. The annual rate at which we generate scrap tires is approximately one tire per capita. Even if tires are to be used as fuel at the points at which they tend to accumulate, the power plants using them must be very small. We have calculated that the tires accumulating in New York, Los Angeles, and Washington, D.C., would support, respectively, power plants of 25 MWE, 8.5 MWE, and 2.4 MWE, that is, plants able to supply the power needs of 15,000 people, 5,000 people, and a single large apartment building.

Capital costs of power plants decrease as size increases. The capital costs of very small plants tend to be in the range of $200 to $300 per kilowatt; capital costs of large plants range between $75 and $125 per kilowatt, and capital costs represent approximately one-half the cost of power production. Assuming that rubber burning and handling modifications would add another 20 to 30 percent to the cost of the plant, power based on rubber burning, by reason of the small plant size, would inevitably cost a great deal more than power from conventional fossil fuel even if tires were delivered free to the plant.

If, however, power production is considered as a means of disposing of tires at low cost and obtaining an offsetting benefit, power production becomes extremely low-cost strategy alternative for the places where there are large concentrations of tires. A subsidy of between $.05 and$.10 per tire, capitalized, would pay the entire capital costs of the power plants that would burn tires, or more than compensate for any differences in capital and operating costs that arise from burning tires. Moreover, there are many activities that would profit from being independent of large power failures, such as those of hospitals and manufacturing plants, the power demands of which could be matched with the scrap tire flows of the cities where they are located to determine the best customer for a tire-fueled plant.

4. How much nonmonetary benefit will be recovered? The principal nonmonetary benefits would be the incremental improvement in community

health or safety that would result from operation of a more dependable emergency power source for a specialized community facility such as a hospital.

5. How long will this strategy be possible? The tire-burning power plants would be feasible for as long as fossil fuel power plants are feasible, that is, twenty years or more.

6. How much of the yearly output of scrap tires could the use absorb? The distribution of scrap rubber, of which tires constitute 59 percent, is such that approximately half is generated within a 100-mile radius of major metropolitan areas. (We have arrived at the figures by accepting the scrap rubber distribution presented in Reference (6). Although there are a few variations, in general the number of scrap tires generated is distributed in roughly the same pattern as scrap rubber generated. Industrialized areas tend to generate a higher proportion of nontire rubber scrap than nonindustrialized areas.)

The rubber-tire-burning plants, therefore, could be expected to operate most economically with respect to roughly half the total number of tires discarded. With respect to the remainder, collection and transportation costs would eliminate the cost advantages accruing near large cities.

7. How much will the strategy change the existing tire market? Power production would not alter the existing market structure at all.

8. How compatible is the strategy with other solid waste management practices? Power production would not affect other solid waste management other than to reduce the flow of tires into it.

Strategy D

End Uses:	Destructive distillation, carbonization, hydrogenization.
Explanation:	The existing tire pyrolysis and hydrogenization processes are too expensive for their products to compete on even terms with petrochemical industry feedstock. This strategy proposes a heavy initial Federally-supported research and development program followed by a bounty arrangement to make early operation profitable and encourage investment in construction of suitable plants once technology for them develops.
1. Charge:	Add a disposal fee tax to the cost of each new tire to be paid into a Federal trust fund.
2. Payment:	(a) Pay to retreaders part of cost of collection and of shipment to destructive distillation plant. (b) After completion of research and development, and of pilot plant programs, pay to operators of destructive distillation, carbon black recovery, or hydrogenization plant, a $.50 per tire bounty for each tire used in the process for a period

of 5 years after commencement of commercial operations.

3. Regulation: None.

4. Education: None.

5. Research and Development: Initially, the Federal government would support research and development of improved processes under provision that patents developed under the research program would be licensed to competitors for a reasonable royalty. The development program would include provision for paying part of the costs of pilot plant construction and operation.

Evaluation

The three processes dealt with in this strategy offer the clearest opportunity to recycle a very large proportion, more than half of each used tire, back into new tire use. Significant amounts of private capital are currently being invested in these processes in the expectation that they will be financially profitable once they have reached commercial scale. For at least one of these processes, profitability is being projected on the basis that its outputs will be able to compete on the market against other sources of the same substances.

1. How soon will the strategy be technically feasible? The strategy itself could not be put into effect immediately, but its effects would not be felt until the processes reached commercial development. Estimates of the time needed to reach commercial scale development for these processes range from 3 to more than 5 years.

2. How much land/air/water residual does the specific use leave? Proponents of the processes assert that they will be nonpolluting. Although this claim may be well founded, available information does not support this assertion. The petroleum refining industry encounters pollution problems in separating the constituents of petroleum from one another, though these problems are not unsolvable. Analogous problems seem likely to arise in separating and storing the gaseous and oil residuals obtained during destructive distillation. To dispose of the carbon residual of destructive distillation will require sulfur emission controls. The gases given off during carbon black recovery must be contained and disposed of. Hydrogenization purports to yield sulfur as one of its saleable products; hydrogen sulfide is an intermediary product that must be controlled and processed to obtain the sulfur.

3. How much cash cost per unit will be unrecovered? Investigations of the hydrogenization process report that sales of its products on the open market will pay its capital and operating costs and return a profit. No reliable figures were available on which to estimate the relative expenses and income that would result from destructive distillation. Carbon black recovery from rubber at the present time is three to four times as costly as carbon black recovery from petroleum, and would only be economically feasible as a disposal process with a subsidy in excess of $1 a tire. Future development, however, may greatly reduce this cost.

4. How much nonmonetary benefit will be recovered? The recycling of rubber constituents would slightly reduce the demand for scarce petroleum resources, but nonmonetary benefits would be slight.

5. How long will this strategy be possible? Execution of the strategy would have a limited duration: the period of development plus 5 years. The industry set in motion by the strategy, however, should be able to continue to function as long as there are large numbers of tires to be disposed of.

6. How much of the yearly output of scrap tires could the use absorb? The destructive distillation process and hydrogenization processes, as they are presently conceived, would be able to absorb all of the output of scrap tires. Carbon black recovery, in its present form, could absorb only about one-third of current scrap tire output without exceeding the demand for carbon black; further development may increase the proportions it could absorb economically.

7. How much will the strategy change the existing tire market? The strategy would cause some change to the existing carbon black market to the extent that the present sources of supply would be replaced by the new plants. The extent of the change would depend upon the development of the new industry. If the existing carbon black manufacturers converted to the new process in order to qualify for the incentive payments, market disruptions would be minimal. The tire industry is in a unique position to use its distribution system as a collection system for scrap tires. The industry also feels, directly, the political and consumer pressure generated by unsatisfactory disposal of scrap tires. The bounty offer might be a sufficient incentive to encourage the tire industry to enter the carbon black manufacturing market and become its own supplier.

8. How compatible is the strategy with other solid waste management practices? The strategy would not affect solid waste management other than to eliminate the problem of tire disposal.

Strategy E

End Uses:	Undetermined
Explanation:	Because the intensity and character of tire disposal and reuse problems vary in different parts of the country, a flexible incentive to state governments may be preferable to a single national incentive program. Such an incentive program would encourage proper disposal of used tires. A supplemental national program to extend tire life and encourage retreading through early tire replacement and educational programs on tire inflation would reduce the number of scrap tires to be disposed of.
1. Charge:	Part of the existing Federal excise tax of \$.10 per pound on new tires and \$.05 per pound on retread rubber would be diverted from the Highway Trust Fund, into which it is now paid, to a tire disposal trust fund.

2. Payment:	A preliminary allocation of the tire disposal trust fund payments for each year would be made among the states, proportionate to tire sales in each. For the first three years, each state would receive its total allocated share, to expend on the capital costs of recycling, or approved end use disposal facilities. Thereafter, a state would be paid the portion of its allocated share corresponding to the number of scrap tires disposed of through an approved use, in the state. Unused portions of the fund would be available for Federally-supported research on advance recycling technology.
3. Regulation:	The Solid Waste Management Office would give initial approval to a series of end uses such as suitably controlled incineration, sanitary landfill of chopped tires, road surfacing, and reef building, and would approve proceedings to consider approving such additional end uses as the states might suggest from time to time. States would be encouraged to enact uniform legislation requiring the replacement of tires showing exposed tread depth indicators as a condition of passing state vehicular safety inspections.
4. Education:	The strategy would provide a continuing public education program explaining the importance of proper tire inflation practices and encouraging replacement of tires when tread depth indicators are exposed.
5. Research and Development:	The strategy would provide a Federally-supported research and development program on destructive distillation, carbon black recovery, hydrogenization and similar advanced recycling processes.

Evaluation

At present, the technology of tire recycling is undergoing very rapid change. None of the existing technologies is satisfactory. Research into processes that have been given desultory consideration for a long time is now receiving substantial private support, and there is an intensive effort underway to identify new recycling opportunities.

At such a time, it would seem advantageous to develop strategies that stimulate the development of new technology and that set in motion interim action that will help reduce the current problem, without making a final commitment to a single form of reuse or disposal.

In addition, tire disposal is a different problem in different parts of the country, and different solutions will have different appeal in various regions. The coastal states, in competing for tourist trade, may have a strong economic incentive for bearing a large part of the cost of reef building. A densely populated metropolitan area that has experienced repeated power shortages may have strong interest in developing an independent power system to operate facilities that must function at all times. Some states have already begun incinerator upgrading programs that are in need of supplemental funding.

This strategy provides the states with an initial fund of seed money to finance facilities that achieve a satisfactory state-of-the-art end use, and a reserve fund to pay capital costs of true recycling plants after recycling technology has developed. The strategy encourages the states to invest state funds in such facilities as well, so that the state can profit from as large a share of future tire fund payments as possible. It generally reinforces state initiative.

1. How soon will the strategy be technically feasible? The strategy permits selection among end uses that are currently feasible.

2. How much land/air/water residual does the specific use leave? The pollutants released by the strategy would depend upon the end uses selected.

3. How much cash cost per unit will be unrecovered? Costs would also vary depending upon the end uses selected by the states.

4. How much nonmonetary benefit will be recovered? In addition to the nonmonetary benefits that have been identified with respect to various end uses, this strategy would be a form of Federal revenue sharing that would emphasize the effectiveness of state governments at a time when such enhancement from revenue sharing is a high priority goal for the Federal government.

5. How long will this strategy be possible? Early disbursements from the allotment funds of the states would be for capital costs of employing current technology; later disbursements would be in capital costs of advanced recycling installations, or, if volume within a state was not sufficient to support a recycling installation, in capital costs associated with utilizing a recycling installation in another state. The advanced recycling procedures could be expected to operate indefinitely and any associated costs would be paid out of current allotment receipts.

6. How much of the yearly output of scrap tires could the use absorb? The strategy would be likely to absorb all scrap tires. The capital investments would be flexible enough to permit the installation of whatever equipment was most suitable for each area. The continuing payments to the state would be greatly in excess of collection and transportation costs, intra-state, of tires, in the possession of small retailers. As a result, it would be in the interest of the state to pay for the collections of all scrap tires within its borders since it would earn a profit on each tire disposed of properly.

7. How much will the strategy change the existing tire market? The strategy would not affect the existing tire market except insofar as retreaders would gain competitive advantage.

8. How compatible is the strategy with other solid waste management practices? The strategy would have varied effects on waste management, depending on the end uses selected. In general, it would appear to have considerable promise as a source of funds to augment solid waste management improvements.

9. Administrative problems. The strategy raises one set of special difficulties. The state, and its subdivisions or contractors, stand to profit from the reported number of tires disposed of through an approved use. Outright failure to build disposal or processing facilities could easily be perceived and dealt with by the administering Federal agency. It will be more difficult to deal with the strong temptation that will appear at several levels of private and public participation; that is, to overstate the number of tires that have been disposed of in an approved use. A system of tire disposal affidavits or returns and an auditing operation will be necessary.

Strategy F

End Uses:	Undetermined.
Explanation:	This strategy is similar in concept to the preceding one. Its principal difference is that it relies upon direct Federal payments to persons disposing of tires in approved uses rather than using the states as a mechanism for making such payments. In many cases the users will be municipal governments. Although the strategy speaks in terms of payments to users, it is clear that in most uses a large fraction of these payments will in turn be paid over to the persons supplying tires to the users; tire retreaders, casing dealers, or tire scavengers. The choice between this strategy and the preceding one will be determined by the form of Federalism preferred by the person making the decision.
1. Charge:	Add a tire disposal tax to the cost of each new tire. The proceeds would then be paid into a Federal trust fund.
2. Payment:	To each approved user of scrap tires pay a bounty equal to the tire disposal tax, for each tire used, in an approved use process.
3. Regulation:	The Solid Waste Management Office would initially approve a group of reuses and end uses without adverse environmental effect. Subsequent proceedings would be available to approve other uses.
4. Education:	None.
5. Research and Development	None.

Evaluation

Other strategies that provide only payments for specified equipment or for retreaders' collection and transportation costs will not provide incentives to reward entrepreneurial development of new collection procedures or utilization processes. This strategy would make disposal of tires into currently approved end uses profitable to the user. It would also provide an incentive for private research and development of new recycling processes that might otherwise be only slightly profitable.

Whether the end use employed under the strategy is one that now exists or one that is to be developed in the future, the payments made at the point of disposal will be distributed in part to the user's suppliers. This will make it economically worthwhile for the large-scale retreader to dispose of his scrap tires through the approved user. This will also make it worthwhile for the retreader to collect tires from small retailers, since he can make a profit on them even if they are not retreadable. Finally, it is likely to support the growth of a tire scavenging effort through which tires heretofore discarded would be retrieved and disposed of through the approved end uses.

1. How soon will the strategy be technologically feasible? The strategy could be used immediately.

2. How much land/air/water residual does the specific use leave? Pollutant production would depend upon the end uses chosen.

3. How much cash cost per unit will be recovered? Cost would depend upon end uses chosen.

4. How much nonmonetary benefit will be recovered? The strategy may be expected to aesthetically enhance areas that have been littered with discarded tires.

5. How long will this strategy be possible? The strategy will be possible indefinitely.

6. How much of the yearly output of scrap tires could the use absorb? The strategy could absorb all scrap tires.

7. How much will the strategy change the existing tire market? This strategy would alter the existing market to the detree that advanced recycling processes changed the sources of supply of raw materials for rubber, and that retreaders gained competitive advantages through reduced costs.

8. How compatible is the strategy with other solid waste management practices? The strategy would in some cases remove tires from the solid waste stream and supply equipment that would assist the management of other solid wastes.

Strategy G

End Uses:	Reef building, destructive distillation, carbon black recovery, hydrogenization.
Explanation:	There are several uses that will require regional collection; for example, ocean dumping, carbon black manufacture, destructive distillation, and hydrogenization. With respect to each of these, the collection and shipping problems will be similar. The costs of the operations for each

of these end uses should be comparable. Receiving and handling costs at a regional center would be similar. Although the capital costs for each of these end uses will be different, each will be a form of disposal cost that would relieve a multi-state problem and, like collection and transportation costs, be appropriately financed through Federally administered procedures. These end uses are compatible and complementary with one another. They require identical collection and transportation systems. Reef building is immediately feasible and could absorb all scrap tires now being discarded, but it would be possible only for a few decades. Carbon black recovery, destructive distillation, and hydrogenization would require a number of years of research and development and plant construction time before they would begin to absorb a large fraction of the annual flow of unrecapped tires.

1. Charge: Add a disposal fee tax to the cost of each new tire to be paid into a Federal trust fund.
2. Payment: (a) Pay retreader part of cost of freight to disposal point.
   (b) Pay operating costs of reef building.
   (c) After the appropriate technology develops, pay a portion of capital costs of carbon black, destructive distillation or hydrogenization plants.
3. Regulation: None.
4. Education: None.
5. Research and Development: Federal support for research and development of destructive distillation, carbon black recovery, and hydrogenization processes.

Evaluation

This strategy selects a presently acceptable, and feasible, end use and several of the more promising long-range opportunities for Federal assistance. Unlike several of the alternative strategies it permits the concentration of research and development efforts on the specified long-range end uses and would permit immediate action to remove tires from the solid waste stream. It would make mere "disposal" (as opposed to functional utilization) of tires unnecessary at any time, without depending on permanent Federal subsidy.

1. How soon will the strategy be technically feasible? Because the first phase of this strategy (reef building) is feasible now, implementation can begin immediately.

2. How much land/air/water residual does the specific use leave? Environmental impacts remain a major uncertainty for this strategy. None

of the end uses except reef building has been developed sufficiently to ascertain whether pollution control will be an obstacle. Testing on reefs has indicated no environmental hazard yet, but has been conducted for only a relatively short time. There is no evidence to suggest that any of these end uses will be as much of a hazard as ordinary incineration.

3. How much cash cost per unit will be unrecovered? In its early stages, this would be a relatively expensive strategy, perhaps the most expensive of all. It would have the advantage of pump priming an economic cycle in which scrap tires would have a positive value. Thus, while unrecovered cost would be considerable for 2 or 3 years, much of this cost would ultimately be recovered in the private sector of the economy.

4. How much nonmonetary benefit will be recovered? Two important nonmonetary benefits would accrue from this strategy. First, the recreational value of coastal waters (both to fishermen and to naturalists) would be enhanced. Second, an important example would be established for the principle that society can make profitable use of its undesirable by-products.

5. How long will this strategy be possible? The strategy can continue indefinitely.

6. How much of the yearly output of scrap tires could the use absorb? The strategy can absorb all of the yearly output except the small percentage of scrap tires normally discarded in remote areas.

7. How much will the strategy change the existing tire market? Some changes would occur, although these changes appear unlikely to upset existing industries to the extent of necessitating major changes in personnel, tools, etc. Retreaders would operate more profitably, thereby providing slightly more competition for low-priced new tires. Suppliers of carbon black to new tire manufacturers would be faced with a new source of competition in the carbon black recovery industry. The extent of the market impact of this strategy would depend partly on the extent to which destructive distillation, carbon black recovery, and hydrogenization are undertaken by companies not already engaged in the manufacture or marketing of rubber tires.

8. How compatible is the strategy with other solid waste management practices? The strategy would not affect solid waste management except insofar as it relieved it of tires.

Strategy H

End Uses:	Increase retreading, increase tire wear (in conjunction with other acceptable reuses or end uses).
Explanation:	The education program to promote retreading and increase tire wear described in Strategy A can be made part of a more comprehensive strategy that includes monetary charges, payments, regulation and research and development.
1. Charge:	(a) Remove existing excise tax from the cost of retread tires.

(b) Add a graduated excise tax to new tires that would range from a high tax for tires having low durability characteristics, or poor retreading characteristics down to zero for tires having the best durability and retreading characteristics. Proceeds form the excise tax would be deposited into a tire disposal trust fund.

2. Payment: (a) Pay retreader from the disposal trust fund part of cost of collection from retailer of all tires turned in by customers.

(b) Pay retreader from the disposal trust fund part of cost of delivery of unretreadable scrap tires to municipal disposal agency or cost of freight to regional disposal facility.

3. Regulation: (a) Require all states to include tire wear indicator criteria or equivalent in automobile safety inspection standards so as to compel early trade-in.

(b) Require tire wear indicator marking in all recapping tread.

(c) Modify Federal new tire safety standards to improve wear and retreading characteristics.

4. Education: (a) Explain to consumer the advantages from the viewpoint of solid waste disposal and consumer costs of buying retreads and the purpose and advantages of early trade-in.

(b) Publicize the purpose and amount of the graduated taxes charged for various kinds of new tires and explain, through labeling and other means, the reasons for the discriminatory taxation.

(c) Explain the importance of tire pressure in extending tire life and encourage once-a-week pressure checks.

5. Research and Development: Provide Federal support for tire retreading research concentrating on possible changes in tire design or rubber compounding in new tires that would enhance the bonding characteristics of used tire carcasses, and on the development of improved adhesives.

Evaluation

This strategy would place the passenger car retreading industry in a more competitive position than has been possible in the past.

1. How soon will the strategy be technically feasible? Immediately.

2. How much land/air/water residual does the specific use leave? See Strategy A.

3. How much cash cost per unit will be unrecovered? Transportation subsidies represent an augmentation of present profits in that they enable retreaders (who have been relieved of the expense of transporting tires themselves) to achieve new efficiencies by expanding their operations or lowering their costs. Increased profits are partically returned to the government through taxes. Federal support for tire retreading research would have a direct impact on future retreading costs, and is therefore at least potentially recoverable.

4. How much nonmonetary benefit will be recovered? None.

5. How long will this strategy be possible? See Strategy A.

6. How much of the yearly output of scrap tires could the use absorb? See Strategy A.

7. How much will the strategy change the existing tire market? This strategy could have a significant impact on sales of various types of tires. The elasticity of the tire market is limited somewhat by the automobile market, and ultimately by the automobile manufacturers. To the extent that individual consumers can exercise choice in their selection of replacement tires, however, the graduated excise tax would be a major factor in retail sales. One likely result would be a reduction (and possible elimination) of the "cheap" new tire market - a market which constitutes a more important percentage of total sales for some tire manufacturers than for others.

8. How compatible is the strategy with other solid waste management practices? The strategy would have no adverse effect on solid waste management.

Strategy I

End Uses: Combining destructive distillation, carbon black recovery, or hydrogenization with power production.

Explanation: Pyrolysis or hydrogenization combined with power production may persent an opportunity for synergistic operation. The destructive distillation process will require a relatively large plant (as contrasted, for example, with a municipal incinerator), and process heat. The aromatics driven off and collected during pyrolysis are the source of the unburned hydrocarbon residual that is troublesome in power production. Taken together these suggest that either as part of a single plant or as coordinated neighboring plants, pyrolysis (generating a coke-like carbon residual) might be more economically effective than either process considered separately.

1. Charge: Add a Federal disposal fee tax to the cost of new tires for deposit into a Federal tire disposal trust fund.

2. Payment: (a) By Federal government to regional authority or to tire manufacturers to cover capital costs of destructive distillation plant.

(b) By Federal government to tire retreaders and other sources of scrap tires to cover partially cost of transportation to destructive distillation plant.

(c) By Federal government to destructive distillation plant operator to cover difference between cost of production of distillates and residual and their market value.

(d) By Federal government to cover marginal costs of equipping power plants to burn residue from destructive distillation plant.

(e) By Federal government to cover marginal expenses, if any, of using destructive distillation plant residue as fuel.

3. Regulation: None.

4. Education: Informing the power industry and municipal power production authorities of the availability of destructive distillation plant residue as fuel.

5. Research and Development (a) Federal supported research into lowering costs of pyrolysis and hydrogenization.

(b) Federally supported research in combustion of destructive distillation and hydrogenization residue.

Evaluation

This strategy would increase the likelihood that a recycling process would be profitable. It maximizes the possibility of giving scrap tires a positive economic value by combining a potentially profit-making process with a potentially cost-reducing process. The most likely location for such a plant would be near a tire-producing plant. The distribution system and, in turn, the tire plant would be a customer for the product of the pyrolysis or hydrogenization plant.

1. How soon will the strategy be technically feasible? This strategy could not be fully implemented until the feasibility of combining destructive distillation with power production has been demonstrated in operational prototypes. In principle, there are no obstacles, but several years might be required even for the development of plants which perform either function on a commercial scale even at a loss.

2. How much land/air/water residual does the specific use leave? Solid waste would be minimized by the use of residual from one part of the process as fuel for the other. Air pollution would probably be no more of a problem than would be the case with a plant powered by conventional sources, since the compostion of the residual from destructive distillation is similar to that of coal.

3. How much cash cost per unit will be unrecovered? This strategy entails a number of potentially unrecoverable costs and the total expense, particularly in the first few years, might be relatively heavy. Some of the costs, such as those of research and development, might eventually

be recovered through resulting increases in the profitability of destructive distillation or hydrogenization.

4. How much nonmonetary benefit will be recovered? Demonstrating the possibility of combining heavy industrial production, pollution abatement, and resource conservation in a single process should provide an example (and encouragement) for other attempts to treat production and conservation as ecologically compatible, rather than antagonistic, competing processes.

5. How long will this strategy be possible? Indefinitely.

6. How much of the yearly output of scrap tires could the use absorb? All except a small percentage of scrap tires normally discarded in remote areas.

7. How much will the strategy change the existing tire market? The strategy will not change the existing tire market at all except for a possible slight improvement in the competition position of retreaders due to the alleviation of disposal costs made possible by government subsidies for scrap tire transportation.

8. How compatible is the strategy with other solid waste management practices? The strategy would have no adverse effect on solid waste management.

Strategy J

End Uses: Expanded retreading.

Explanation: At present, many bus companies do not buy tires for their buses, but instead rent tire mileage from tire manufacturers. In the typical arrangement, the bus company pays for tire service for a fixed number of vehicles. The tire manufacturer maintains one or more full-time employees in the bus terminal. The manufacturer's representative checks tire pressure and condition of tread. He decides when a tire should be taken out of service for recapping. The tires supplied are susceptible to multiple recapping and are in fact typically recapped several times before being discarded. Under such an arrangement, the manufacturer has an incentive to make his new tires wear as long as possible and to enhance their retreading characteristics. In this strategy, these practices are extended to privately owned automobiles. Local service stations would serve as agents for manufacturers, checking the tire pressure and condition at the time of gasoline purchase, and replacing tires when necessary. Used tires would be returned to the manufacturer for retreading.

1. Charge: After satisfactory completion of the first phase of the research and development program, a large excise tax ($5) would be added to the sales price

		of new and retreaded tires.
2.	Payment:	None.
3.	Regulation:	None.
4.	Education:	Inform the public, tire manufacturers, and service stations of the potential benefits to be obtained from tire maintenance contracts.
5.	Research and Development	(a) Federally financed pilot programs would seek to measure the reduction in tire consumption and tire costs that would result from an arrangement in which the manufacturer retained title to the tires it made. (b) Federally supported research and development on tire design and adhesives would seek to improve bonding characteristics.

Evaluation

This is the only strategy which would place responsibility for tire maintenance entirely in professional hands. It therefore has the advantage of sweetening the pot (of longer tire life and increased retreadability) with an assurance of increased motoring safety and reliability for the consumer and a probability of lowering his total tire costs.

There are two major difficulties which may be encountered with this strategy. First, it creates a restraint on trade. A tread-use contract would not leave an individual consumer as free to switch to a different make of tire as he is in the existing market. Second, there is a high degree of coercion by the Federal government against the consumer and the retailer. Even though this strategy involves no binding regulations, the imposition of a $5 excise tax would force every tire company to switch to a rental system to remain competitive with the first company to switch. Resistance by the industry is a distinct possibility, particularly since the reaction of consumers to a large tax would undoubtedly support the manufacturers' position. Thus, it is likely that this strategy could not be implemented successfully without prior assurances from the tire manufacturers that the desired change in the tire market could be effected.

1. How soon will the strategy be technically feasible? Immediately.

2. How much land/air/water residual does the specific use leave? No active pollutants are generated by the retreading industry. Buffings, the powdered rubber that is ground off the face of used tires before retreading, are produced in the amount of 94.7 million pounds a year, of which 1 million is used by the reclaiming industry and the remainder dumped.

3. How much cash cost per unit will be unrecovered? The cost of Federally financed educational programs and research and development would be low even at the outset, and would diminish as the advantages of tire maintenance contracts became common knowledge. On the other hand, the cost to consumers would be high enough to cause protests if tire companies did not act quickly to provide the intended rental alternative.

4. How much nonmonetary benefit will be recovered? For participating consumers, the efforts involved in tire maintenance and periodic purchase would be eliminated.

5. How long will this strategy be possible? Indefinitely.

6. How much of the yearly output of scrap tires could the use absorb? As noted under Strategy A, one of the drawbacks of retreading is that it does not provide an end use for tires, but merely reduces the rate at which tires are generated. If all tires were retreaded, however, this reduction would be substantial, as much as 50 percent, assuming they were manufactured to enhance retreadability and professionally maintained.

7. How much will the strategy change the existing tire market? Strategy J would produce far-reaching changes, despite the nominal lack of Federal regulation. The most conspicuous changes would be at the retail level, where tire dealers would find their business drastically reduced and service station personnel would have to adapt to a new set of procedures. An undesirable consequence would be the inevitable situation in which a consumer decides he does not have time to wait for a tire change at the time the manufacturer's agent decides this change should be made. One remedy would be to enact a small penalty, to be added to the consumer's bill from the tire owner, for each occasion on which the recommended tire change is postponed.

8. How compatible is the strategy with other solid waste management practices? The strategy would not interfere with solid waste management.

Strategy K

End Uses: Undetermined.

Explanation: At the present time, the petroleum products from which synthetic rubber is made are available in adequate quantities to meet current needs. Forecasts of consumption rates, and reserves of petroleum, however, indicate that commercially extractable amounts will be in short supply within the next 20 years. Although rubber synthesis uses only a small fraction of the total petroleum consumer and existing recycling technology will not be competitive with petroleum as a source of feedstock for rubber systhesis for some time, the annual discard of scrap tires is a resource that should not be destroyed but rather stored until the time, 2 to 3 decades from now, when declining supplies of petroleum will make recycling of scrap tires highly desirable and economically feasible. Stockpiling whole tires would require very large storage sites. If the tires were chopped, however, the space needed for storage and shipping would be much less. The entire annual national output could be stored in 50-foot piles, in a space of only 150 acres per year at the current rate of discard. Ten regional disposal sites would require an area of 300 acres each, to accumulate the national tire discard over 2 decades. Alternatively, disposal of such quantities in strip mines or existing excavations might be less objectionable to neighboring communities than above-surface storage. As is now being done with municipal waste, recreational value might be obtained by building higher hills out of the stored rubber that could serve as ski slopes during the storage period.

1. Charge:	Add a disposal fee tax to the cost of new tires to be paid into a Federal trust fund.
2. Payment:	(a) Pay retreader part of cost of transportation to local chopping facility out of trust fund. (b) Pay municipality capital and operating cost of tire chopping facility and cost of shipment to regional storage site out of trust fund. (c) Federal government to own and operate regional chopping tire storage sites, paying land purchase and operating costs out of trust fund.
3. Regulation:	None.
4. Education:	None.
5. Research and Development	Research and development of destructive distillation, carbon black recovery, hydrogenization and the recycling technologies to continue with Federal assistance.

Evaluation

There are a number of drawbacks to all of the present end uses for scrap tires. The placing of tires in landfill or roadbeds disposes of them but makes them unavailable for future use. Incineration and power production, even if emission controls are satisfactory, release matter to the atmosphere that will be needed when petroleum is in short supply. Reef building is suspect because however beneficial it may appear, it is likely to be thought of as ocean dumping and its long-range effects on the ocean are still unknown. From the viewpoint of preventing damage to the environment, stockpiling tires disposes of them with less environmental perturbation than any other end use and concentrates the undesirable aesthetic impact of the accumulation. Once set in motion, this strategy would tend to encourage private research and development of methods of recycling tires profitably by increasing and concentrating the available supply. It would tend to discourage the financing of recycling technologies that were only marginally profitable.

Its principal drawback is political. It has the initial appearance of a policy of inaction, of postponing a decision because it is difficult, of paying good money for trash. It would only succeed if the public were convinced that technology is developing through which the stockpile will eventually become valuable.

1. How soon will the strategy be technically feasible? The strategy could be put into effect immediately.

2. How much land/air/water residual does the specific use leave? The strategy has no apparent residual. Rainwater leaching through chopped rubber produces no measurable effluent; wind dispersal of the chopped rubber could be inexpensively controlled by spraying concrete grout over the stockpile as it reaches the desired height.

3. How much cash cost per unit will be unrecovered? Initially, the strategy would return none of its costs, that is, the cost of collection, chopping, transportation, land and stockpiling would be paid out of the current collected tax but would not be repaid during the stockpiling. The eventual repayment, however, would be made, by definition, at that time when, by reason of development of recycling technology, demand for scrap rubber had so far exceeded supply that the stockpile could sell at a price in excess of its cost.

4. How much nonmonetary benefit will be recovered? The stockpiling strategy would increase the incentive to the retreaders to collect used tires from all retailers, or in the absence of such collections, for retailers to pay the cost of transportation to chopping facilities.

It would encourage scavenging of tires heretofore improperly disposed of for purposes of collecting the bounty. By reason of these two effects, it would reduce the aesthetic insult created by tires heretofore disposed of improperly. The recreational use of chopped rubber ski hills could be an additional benefit.

5. How long will this strategy be possible? The strategy can be employed until all stockpiled scrap tires have been absorbed by the new recycling industry and the capacity of that industry is large enough to absorb the then current flow of scrap tires.

6. How much of the yearly output of scrap tires could the use absorb? The strategy would absorb all of the current output of scrap tires.

7. How much will the strategy change the existing tire market? By paying part of retreaders' collection costs, the strategy would tend to improve the competitive position of retreading with respect to inexpensive new tires.

8. How compatible is the strategy with other solid waste management practices? The strategy would remove tires from the solid waste stream and would equip municipal solid waste disposal authorities with chopping and shredding equipment that could be used to compost or otherwise prepare other waste for disposal in sanitary landfill or by incineration.

APPENDIX A

METHODOLOGY FOR SELECTING STRATEGIES

As the main body of the report indicates, strategy development began with investigations of possible end uses. Once end uses including their benefits, costs and other constraints had been identified, sets of incentives likely to promote each end use were associated with them, then compatible sets of end uses were grouped together and their incentives examined for possible complementary, or conflicting, influence. When the influences were deemed complementary, the grouping was designated a strategy.

After strategies had been designated, the evaluation criteria were developed. We began with the criteria used in the Solid Waste Management Office study, The Automobile Cycle: An Environmental and Resource Reclamation Problem:

(1) minimize environmental damage;

(2) conserve natural resources;

(3) minimize economic disruption;

(4) minimize administrative procedures.

These did not appear to cover all the issues necessary for selecting a tire recycling strategy chiefly because of the need to include criteria that would measure graduated degrees of feasibility, and because administration procedures were difficult to assess before they had been worked out in considerable detail. Six criteria were nominated by the project manager and additional candidate criteria were solicited from staff members. Duplicate criteria were eliminated and a preliminary criteria list circulated for comment.

The list grew from six criteria to eleven and then was reduced to eight, after discussions in which descriptive wording was revised and the clarifying definitions set out on pages 55-56 of the report were agreed upon.

In order to establish the relative weight of the different criteria, the project staff were then requested to allocate a total of 100 units of value among the eight criteria. The resulting allocations were then discussed in the formalized evaluation procedure described in "Synergi - A New Technique for Evaluation and Planning", IRT-P-6/1, similar in purpose to the Solid Waste Management Office DARE procedure.

The staff members placing the lowest and highest values on each criteria were asked to explain their scores. Typically, divergence of weighting was the result of different interpretations of the criterion being applied. Definitions were further refined and the process repeated. The weighting allocations converged considerably. Mean averages of the staff's second round of criteria weights were then used to establish the relative importance of the criteria.

A matrix displaying the alternative strategies vertically and criteria horizontally was prepared for use in determining the rating of each strategy under each criterion.

A rating scale was prepared under which the degree to which a strategy achieved the value expressed by a criterion was expressed in four descending values; e.g., how soon will strategy be technically feasible?

(a) now

(b) within 5 years

(c) 5-10 years

(d) more than 10 years

These four gradations were, for computation purposes, assigned the descending numerical values 8, 4, 2 and 1.

Staff members then filled in the matrix, showing for each strategy, one of the four value levels (see Figure 2.1). The values chosen were discussed; again the high and low rates were explained and each vote taken again. On the second vote taken, voting was either unanimous before discussion or a concensus was reached after discussion. The value recorded under each criterion was then multiplied by the weight that had earlier been assigned to the criterion.

The scoring for the strategies was carried out by two methods. In the first, all the weighted criteria values for each strategy were added into a single numerical score. In the second, the criteria were divided into two classes: technical and economic/political, and the numerical values for each displayed separately.

The conclusions were as follows:

Unitary Ranking	Divided Ranking	
	Technical	Economic/Political
K	K	C
E	A,H,J	D,E,G
B,F	B,E,F	B,F,I
D,G	D,G,I	K
C	C	A,H
A,H		J
J		
I		

The lowest four strategies under each of the two categories were eliminated, leaving E, B and F standing as the highest group of strategies and E, with the second highest overall score, as the preferred strategy.

FIGURE A-1
EVALUATION MATRIX

Technical Aspects

	$C\ 1^{(10)}$	$C\ 2^{(22)}$	$C\ 5^{(6)}$	$C\ 6^{(13)}$	Totals
A	80	176	48	13	330
B	80	88	48	104	320
C	80	44	48	52	224
D	40	88	48	104	280
E	80	88	48	104	320
F	80	88	48	104	320
G	40	88	48	104	280
H	80	176	48	26	320
I	40	88	48	104	280
J	80	176	48	26	330
K	80	176	24	104	384

Economic and Political Aspects

	$C\ 3^{(10)}$	$C\ 4^{(13)}$	$C\ 7^{(10)}$	$C\ 8^{(13)}$	Totals
A	52	26	40	26	144
B	26	26	80	52	184
C	52	26	80	104	262
D	52	26	80	52	210
E	26	52	80	52	210
F	26	26	80	52	184
G	26	52	80	52	210
H	26	52	40	26	144
I	52	26	80	26	184
J	52	52	10	26	140
K	13	26	80	52	171

Legend:

The left-hand column displays the eleven strategies identified by letter. The eight criteria identified as C1, C2, etc. appear at the top of each column of values. The number appearing in parentheses next to each criterion is the weight assigned to it.

The values appearing on the matrix are the product of the figure indicating the degree to which each strategy satisfied a criterion and the criteria weights.

Cost and Quantity Estimates

As noted above, cost estimates for alternative disposal and reuse systems are based on approximate fiaures. Because cost figures for some strategies are sufficiently uncertain to make dollar approximations misleading, the evaluation process used four broad classes of economic effect to categorize per tire costs: substantial net benefit, small net benefit, small net cost and substantial net cost.

Based on this classification system the strategies compare as follows:

Table A-1

Strategy	Net Benefit	Net Cost
A	small	
B		small
C	small	
D	small	
E		small
F		small
G		small
H		small
I	small	
J	small	
K		large

A similar classification system was used to measure what proportion of a year's output of scrap tires could be absorbed by a given strategy with the following results:

Table A-2

Strategy	Proportion of Tires Absorbed			
	0-30%	30%-60%	60%-80%	80%-100%
A	x			
B				x
C			x	
D				x
E				x
F				x
G				x
H		x		
I				x
J		x		
K				x

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